5-9181

ADM
Acres Davy McKee

ACRES DAVY MCKEE ENGINEERING INC.

ONTARIO RESEARCH FOUNDATION

DENISON MINES LTD.

DEPARTMENT OF SUPPLY AND SERVICES

COMPARISON OF BIOSORPTION CAPACITY OF DENISON MINE ISOLATES WITH ORGANISMS PREVIOUSLY ASSESSED
DSS FILE NO. 15SQ.23440-5-9181

CONTRACT REPORT NO. OSQ85-00223

CONTRACTOR: Acres, Davy, McKee Eng. Inc.

MICROMEDIA

July 30, 1986

146 pp

TABLE OF CONTENTS

		Page No.
Executive Summary		1
Recommendations For Further Work		4
Program Objective		5
Phase I Report - Development of Detailed Workplan		
1.	Introduction	6
2.	Production of Biomasses and Performance of Testwork	6
3.	Evaluation of Biomasses	8
Phase II Report - Performance of Testwork		
1.	Production of Biomass	10
1.1	Stock Cultures	10
1.2	Culture Medium	10
1.3	Culture Conditions	12
1.4	Large-Scale Cultures of Test Organisms	12
1.4.1	Actinomycete	12
1.4.2	Acidophilic Rhizopus Species	14
1.4.3	Rhizopus arrhizus and Acidophilic Penicillium Species	14
1.5	Harvesting of Biomass	15
1.6	Heat Shocking	15

TABLE OF CONTENTS (Cont'd.)

		Page No.
1.7	Results and Discussion	16
1.7.1	The Organisms	16
1.7.2	Culture Conditions	17
1.7.3	Biomass Description	17
1.7.4	Conclusions	19
1.8	Comments on Biomass Production	19
2.	Biosorption Studies	20
2.1	Experimental Procedures	20
2.1.1	Batch Adsorption Rate Tests	21
2.1.2	Batch Equilibrium Adsorption Tests	22
2.1.3	Batch Desorption Rate Tests	23
2.1.4	Equilibrium Desorption Tests	23
2.1.5	Continous Actinomycete Shaker Tests	24
2.1.6	Column Tests	25
2.2	Results and Discussion	26
2.2.1	Batch Adsorption Tests	26
2.2.2	Batch Desorption Tests	30
2.2.3	Actinomycete Continuous Tests	33
2.2.4	Column Tests	35
	Phase III Report - Evaluation of Biomasses	
1.	Introduction	90
2.	Penicillium	92
2.1	Flowsheet Development	92
2.1.1	pH Adjustment	92

TABLE OF CONTENTS (Cont'd.)

		Page No.
2.1.2	Biomass Loading and Elution	92
2.1.3	Selection of Eluant	93
2.1.4	Yellowcake Precipitation	94
2.1.5	Eluant Carbonation	94
2.1.6	Biomass Fermentation	94
2.2	Conceptual Flowsheet	95
2.3	Design Criteria	97
2.4	Culture Requirements and Cost of Nutrients	97
2.5	Ease of Scale-Up	99
2.5.1	Mass and Energy Balance Considerations	99
2.5.2	Process Control	100
2.5.3	Liquid/Solid Contacting	100
2.5.4	Liquid/Solid Separation	101
2.5.5	Materials Handling	101
2.5.6	Type of Equipment and Materials of Construction	101
2.5.7	Generation of Contaminants and Desired Products	102
2.5.8	Nutrient Requirements	102
2.6	Major Technical Problems	102
3.	Actinomycete	103
3.1	Flowsheet Development	103
3.1.1	General	103
3.1.2	Liquid/Solid Contacting	104
3.1.3	Liquid/Solid Separation	104
3.2	Design Criteria	104
3.3	Culture Requirements and Cost of Nutrients	105
3.4	Major Technical Problems	106

TABLE OF CONTENTS (Cont'd.)

		Page No.
4.	Rhizopus Arrhizus	106
4.1	Flowsheet Development and Conceptual Flowsheet	106
4.2	Design Criteria	107
4.3	Culture Requirements and Cost of Nutrients	107
4.4	Ease of Scale-Up and Major Technical Problems	107

EXECUTIVE SUMMARY

In response to a request for proposal from the Department of Supply and Services, a joint program was established by Acres Davy McKee Engineering Inc., the Ontario Research Foundation and Denison Mines Ltd. to examine the biosorption performance of three acidophilic fungi isolated from one of the Denison leach stopes, and to compare this with those organisms studied previously under DSS Contract No. 26SQ.23440-4-9172.

A contract for the program was awarded to the consortium under DSS File No. 15SQ.23440-5-9181.

The program consisted of three phases:

Phase 1 - Development of Detailed Work Plan
Phase 2 - Performance of Testwork
Phase 3 - Evaluation of Biomasses

The four biomasses studied in the program were: acidophilic Penicillium, an acidophilic Rhizopus - like organism, a neutrophilic Actinomycete and Rhizopus arrhizus.

Details of the program have been outlined in the proposal issued to DSS (ADM No. S3200.42) and are also discussed within this report. In general, the project involved determining the biomasses' growth rates, physical characteristics and adsorption properties.

The results of the study are summarized by the following conclusions:

(1) Growth rates for the acidophilic Penicillium species and the Actinomycete were 0.15 g dry solids/L/day and 0.60 g dry solids/L/day, respectively. The Rhizopus arrhizus growth rate, although not measured, was determined to be similar to that of Penicillium.

(2) Initial productivities of the acidophilic Rhizopus species were poor. It was subsequently identified that the culture obtained from CANMET was in fact a contaminant. The production of this species was therefore terminated.

(3) The Penicillium species was determined to have the best physical characteristics of all the biomasses. It is very resilient and disperses well in the reactor. The pellets are also sufficiently dense to settle rapidly. Filtration of the Penicillium is effective. The R. arrhizus formed large pellets which required shredding prior to adsorption testing. Upon shredding, the biomass behaved similar to Penicillium. The Actinomycete is fibrous in nature with the physical appearance of glue when in solution. Although dispersion was good, filtration and settling was poor.

(4) Overall, the Penicillium species showed the best adsorption and elution characteristics. Up to 25 mg U per g dry biomass was loaded from pH 4.0 Denison Minewater in batch tests. Essentially 100% desorption was achieved from this biomass within 15 minutes using 0.1N Na_2CO_3 eluant. In continuous column testing, Penicillium exhibited similar adsorption performance but much poorer elution (about 40% maximum elution).

(5) Actinomycete exhibited similar loading performance to Penicillium. However, desorption was slightly less efficient with approximately 95% elution achieved within 15 minutes using 0.1N Na_2CO_3 eluant.

(6) The R. arrhizus showed uranium loadings of only 10 to 15 mg per g biomass from pH 4.0 minewater. Elution in batch tests was poor (approx. 36%). However, 100% elution was achieved in the column tests using 0.1N Na_2CO_3.

(7) Yttrium loading on to all of the biomasses tested was negligible.

(8) Adsorption from minewater as-received (pH 2.0) was poor. Adjustment to pH 4.0 was necessary to affect acceptable uranium loading.

(9) Based on its attractive physical characteristics and good loading/elution performance, Penicillium was chosen as the most suitable biomass for scale-up. R. arrhizus (after shredding) also showed suitable scale-up properties. The Actinomycete, however, is not suitable to commercial operations due to its "gluey" nature.

(10) The most appropriate system for biomass loading/elution was determined to be packed bed columns, employing split-elution. The remainder of the system would be similar to those found in conventional uranium mills. Both the Rhizopus and Penicillium species could be adapted to such a system. However, the Actinomycete could not be used due to the lack of acceptable flowrates.

RÉSUMÉ POUR LA DIRECTION

En réponse à un appel d'offre lancé par le Ministère des approvisionnements et services, un programme conjoint a été mis sur pied par Acres Davy McKee Engineering Inc., la Fondation de l'Ontario pour la recherche et Denison Mines Ltd., dans le but d'examiner la biosorption de trois champignons acidophiliques isolés des gradins de filtration de Denison et de comparer ces résultats avec ceux des organismes étudiés auparavant aux termes du contrat n° 26SQ.23440-4-9172 du MAS.

Un contrat a été accordé au consortium pour ce programme et il porte le numéro de dossier MAS 15SQ.23440-5-9181.

Le programme se divisait en trois phases:

1re phase - Établissement de plans de travail détaillés
2e phase - Déroulement des tests
3e phase - Évaluation des biomasses

Les quatre biomasses étudiées étaient: le Penicillium acidophilique, un organisme semblable à Rhizopus acidophilique, un Actinomycete neutrophilique et Rhizopus arrhizus.

Les détails du programme ont été exposés dans le projet présenté au MAS (ADM N° S3200.42) et sont aussi traités dans ce rapport. En général, l'objet du projet était de déterminer les taux de croissance des biomasses, leurs caractéristiques physiques et leurs propriétés d'adsorption.

Les résultats de l'étude peuvent se résumer par les conclusions suivantes:

1) Les taux de croissance de Penicillium acidophilique et de Actinomycete étaient de 0,15 g de matière sèche solide/L/jour et de 0,60 g de matière sèche solide/L/jour, respectivement. Le taux de croissance de Rhizopus arrhizus, bien que non mesuré, a été jugé semblable à celui de Penicillium.

2) La productivité initiale de l'espèce Rhizopus acidophilique était pauvre. On a, par la suite, reconnu que la culture obtenue de CANMET était, en fait, un contaminant. Par conséquent, la production de cette espèce a été discontinuée.

3) On a déterminé que, de toutes les biomasses, l'espèce Penicillium avait les meilleures caractéristiques physiques. Elle est très résistante et se disperse bien dans le réacteur. Les boulettes sont aussi assez denses pour se déposer rapidement. La filtration de Penicillium est efficace. Le R. arrhizus formait de grosses boulettes qu'il fallait déchiqueter avant de faire les tests d'adsorption. Après le déchiquetage, la biomasse se comportait comme Penicillium. Actinomycete est de nature fibreuse et présente l'apparence physique de la colle lorsqu'en solution. Bien que la dispersion ait été bonne, la filtration et la stabilisation étaient pauvres.

4) En général, on a observé que l'espèce Penicillium avait les meilleures caractéristiques d'adsorption et d'élution. Au cours de tests discontinus, on a obtenu des fixations allant jusqu'à 25 mg d'U par g de biomasse sèche à partir de l'eau de mine de Denison dont le pH était de 4. En fait, on a obtenu une désorption de 100 % à partir de cette biomasse, dans une période de 15 minutes, en employant l'éluant 0,1N Na_2CO_3. Dans les tests continus en colonnes, Penicilliumn a donné une adsorption semblable, mais une élution beaucoup plus faible (environ 40 % au maximum).

5) On a constaté que Actinomycete avait des capacités de fixation semblables à Penicillium. Toutefois, la désorption était légèrement moins efficace, soit environ une élution de 95 % dans une période de 15 minutes en employant l'éluant 0,1N Na_2CO_3.

6) R. arrhizus n'a donné que des fixations de 10 à 15 mg par g de biomasse à partir de l'eau de mine de pH 4. Dans les essais discontinus, l'élution était faible (environ 36 %). Toutefois, dans les essais en colonnes, on a obtenu une élution de 100 % en employant 0,1N Na_2CO_3.

7) Les fixations de yttrium sur toutes les biomasses soumises aux essais étaient négligeables.

8) L'adsorption à partir de l'eau de mine telle que reçue (pH 2) était faible. Il était nécessaire de ramener le pH à 4 pour obtenir des fixations d'uranium acceptables.

9) En raison de ses caractéristiques physiques intéressantes et de sa bonne capacité de produire des fixations/élutions, Penicillium a été choisie comme étant la biomasse la plus adéquate pour l'exploitation.
R. arrhizus (après déchiquetage) a aussi présenté des propriétés intéressantes. Toutefois, Actinomycete ne convient pas à l'exploitation commerciale en raison de sa nature "gluante".

10) On a déterminé que le système le plus approprié pour la fixation/l'élution de la biomasse étaient les colonnes à garniture en faisant appel à l'élution fragmentée. Le reste du système serait semblable à ceux qu'on trouve dans les usines d'uranium ordinaires. Les deux espèces Rhizopus et Penicillium pourraient être adaptées à un tel système. Toutefois, Actinomycete ne pourrait pas être utilisée en raison de l'impossibilité d'obtenir un débit acceptable.

RECOMMENDATIONS FOR FURTHER WORK

The results from the program indicate that a number of areas exist which require further investigation beyond the scope of this project. In particular, the following elements should be addressed:

(1) Optimization of the culture conditions and selection of the most cost efficient growth.

(2) Identification of the growth-limiting nutrients.

(3) Evaluation of immobilizing agents to produce more physically viable Actinomycete cultures.

(4) Evaluation of the elution characteristics of Penicillium and Actinomycete to achieve better elution in continuous studies.

(5) Evaluation of R. arrhizus loading properties to achieve better uranium adsorption.

(6) More detailed evaluations on the use of EDTA as a regenerant to determine the performance in repeated loading/elution cycles.

(7) Evaluation of the ability of the biomasses to withstand the pressure drops experienced in large-scale columns.

(8) Determination of biomass resistance to commercial-scale materials handling systems.

(9) Determination of biomass life.

(10) Development of a process flowsheet that is simple so as to minimize problems associated with lack of sophistication of underground operators.

(11) Development of the biomass to enable adsorption/desorption at a pH 2.0, thereby overcoming the costly need for pH adjustment.

PROGRAM OBJECTIVE

The objective of the program was to investigate on the bench scale the suitability of three organisms; acidophilic Penicillium, an acidophilic Rhizopus-like organism and a neutrophilic Actinomycete; as biosorbents for uranium and yttrium, and to compare their performance with that of the Rhizopus arrhizus organism previously studied.

To accomplish these objectives the following phases of the program were carried out:

Phase 1 - Development of Detailed Work Plan

Phase 2 - Performance of Testwork
- a) Biomass Production
- b) Adsorption Studies

Phase 3 - Evaluation of Biomasses

Details of these investigations are outlined in the following sections.

PHASE I REPORT

DEVELOPMENT OF DETAILED WORKPLAN

1. PRODUCTION OF BIOMASS

1.1. STOCK CULTURES

Three isolates (from the underground stopes at Denison Mines) which were identified as an acidophilic Penicillium species, an acidophilic Rhizopus species and a neutrophilic Actinomycete respectively, were received from Dr. R.G.L. McCready, CANMET, as Agar cultures in sealed petri plates. A fourth culture, Rhizopus arrhizus, ATCC 6204 was forwarded to Ontario Research at a later date.

All four cultures were inoculated into dilute nutrient broth media, pH 4.5, and incubated with shaking at room temperature. Transfers to Agar slants were made from 48 hour broth cultures of each organism to provide viable cultures for storage. Stock cultures were stored at 4°C.

The growth characteristics of the acidophilic Rhizopus species were not as expected with no growth being detected in dilute nutrient broth, pH 4.5. Following several attempts to establish satisfactory growth from the original stock cultures at either pH 4.5 or pH 6.0, a second stock culture was requested from CANMET. Good growth was established initially with this second culture of Rhizopus species on the nutrient broth medium, pH 4.5.

1.2 CULTURE MEDIUM

Satisfactory growth was obtained with all of the test cultures in the dilute nutrient broth/glucose medium (pH 4.5) recommended by Dr. R.G.L. McCready. This medium had been found to better support the growth of the isolates from Denison Mines. When good growth was also noted with the R. arrihizus in the medium, it appeared reasonable to select this for the production of biomass throughout the study.

- Evaluate uranium and yttrium loading at up to eight liquid/solid ratios at 4°C and 20°C for up to three pH values.

- Carry out up to 5 Fe^{3+}, Ca^{2+}, Cl^-, SO_4^{2-}, PO_4^{3-}, TOC and TSS tests to study their effects on loading.

x) Conduct breakthrough column tests for the four chosen biomasses.

- Develop breakthrough curves for U and Y.

- Assay up to 5 effluent samples for Fe^{3+}, Ca^{2+}, Cl^-, SO_4^{2-}, PO_4^{3-}, TOC, TSS.

ix) Obtain U and Y loaded biomasses for elution studies.

xii) Conduct stir tank uranium and yttrium elution tests for the chosen biomasses.

- NaCl, H_2SO_4 and Na_2CO_3 eluants.

- Conduct equilibrium stir tank elution tests for uranium and yttrium at up to three reagent concentrations and at 20°C.

xiii) Conduct repeated adsorption/desorption column tests for the four chosen biomasses to study the effect of regeneration using EDTA and changes in particle size distribution. Conduct up to twenty cycles for the study.

3. EVALUATION OF BIOMASSES

The three biomasses will be evaluated and compared with the reference biomass (Rhizopus arrhizus) selected from the previous study. The biomasses will also be compared with one another based on the tests conducted in Phase II.

For each biomass, the following activities will be performed:

a) Evaluate results of tests conducted in Phase II and identify general flowsheet for the bioadsorption process.

b) Select the most appropriate solid/liquid contacting system for the biomass. This will involve the consideration of the following parameters.

- review of conventional solid/liquid contacting systems.
- review of design and operating criteria for such equipment.
- assessment of design and operating criteria for the biomass process in comparison with above.
- definition of the optimum solid/liquid contacting system.
- identification of any requirements for equipment modification, special maintenance schedules.
- materials of construction considerations.

c) Prepare process description and process definition.

d) Evaluate ease of scale-up. The scale-up study for the biomass process will involve a critical evaluation of the different factors that impact on this exercise. These include:

- mass and energy balance considerations
- relative costs of biomass production
- simplicity of operation
- process control
- ease of scale-up

PHASE II REPORT

PERFORMANCE OF TESTWORK

1. PRODUCTION OF BIOMASS

1.1. STOCK CULTURES

Three isolates (from the underground stopes at Denison Mines) which were identified as an acidophilic Penicillium species, an acidophilic Rhizopus species and a neutrophilic Actinomycete respectively, were received from Dr. R.G.L. McCready, CANMET, as Agar cultures in sealed petri plates. A fourth culture, Rhizopus arrhizus, ATCC 6204 was forwarded to Ontario Research at a later date.

All four cultures were inoculated into dilute nutrient broth media, pH 4.5, and incubated with shaking at room temperature. Transfers to Agar slants were made from 48 hour broth cultures of each organism to provide viable cultures for storage. Stock cultures were stored at 4°C.

The growth characteristics of the acidophilic Rhizopus species were not as expected with no growth being detected in dilute nutrient broth, pH 4.5. Following several attempts to establish satisfactory growth from the original stock cultures at either pH 4.5 or pH 6.0, a second stock culture was requested from CANMET. Good growth was established initially with this second culture of Rhizopus species on the nutrient broth medium, pH 4.5.

1.2 CULTURE MEDIUM

Satisfactory growth was obtained with all of the test cultures in the dilute nutrient broth/glucose medium (pH 4.5) recommended by Dr. R.G.L. McCready. This medium had been found to support well the growth of the isolates from Denison Mines. When good growth was also noted with the R. arrihizus in the medium, it appeared reasonable to select this for the production of biomass throughout the study.

The medium as recommended by Dr. McCready consisted of:

Dehydrated nutrient broth (Difco or Gibco)	-	0.8 g
Glucose (BDH)	-	10.0 g
Distilled water	-	1000 ml

Prepared medium was sterilized by autoclaving at 15 psi for 20 minutes. The pH of the cooled medium was then adjusted aseptically to 4.5, or if possible to 2.3 by the addition of sterile dilute sulphuric acid solution (15g H_2SO_4/100 ml). Solid medium for the inoculation of slant cultures was prepared by adding 15g Agar/L of medium. The pH of the medium was adjusted to 4.5 using sterile dilute sulphuric acid solution when the sterilized medium had cooled to 45°C. Controls were run throughout these manipulations to ensure that contamination was not introduced during the pH adjustment step.

In preliminary tests, it was found that with the Actinomycete growing in the dilute nutrient broth medium, pH 4.5, the glucose consumption was low i.e. less than 1 g/L in 12-16 hr and therefore the glucose concentration was reduced to 5 g/L.

An alternate medium was investigated for the culturing of the Actinomycete. Tests were conducted in shake flasks and the dilute nutrient broth medium was supplemented with different concentrations of tryptone (0.5 - 2.0% w/v). It was found that the biomass yield was higher than with the dilute nutrient broth medium. However, the gelatinous nature of the resultant biomass made it impossible to recover it easily by filtration, particularly at the highest tryptone concentrations. It was therefore preferable to use the nutrient broth/glucose medium throughout the study.

1.3 CULTURE CONDITIONS

Growth from each culture was inoculated into aliquots (100 mL) of the nutrient broth medium pH 4.5 and incubated with shaking at room temperature (23°C), 27°C and 32°C respectively. The acidophilic Rhizopus and Penicillium cultures were inoculated into the broth adjusted to pH 2.3 and these cultures were also incubated at the three different temperatures with shaking.

1.4 LARGE-SCALE CULTURES OF TEST ORGANISMS

1.4.1 Actinomycete

The Actinomycete cultures were conducted in 4.0 x 7.5L Microferm fermenters (New Brunswick Scientific). Operating volumes were 5.0 - 5.5L. Each fermenter was equipped with a reservoir for the aseptic addition of medium.

The fermenters were inoculated with a 5% (v/v) inoculum of a shake flask culture (48 hr) of the neutrophilic Actinomycete. The cultures were mechanically stirred at 250 rpm at room temperature with aeration (2L/min).

Biomass production was monitored by withdrawing aliquots (100ml) of the culture and recovering the mycelium by filtration (0.45 micron filters). The samples were dried in vacus at 37°C.

When growth was established in each fermenter, a continuous batch mode of operation was initiated. Between two to three litres of microbial suspension were withdrawn from each fermenter at 12 hr intervals and replaced with sterile broth which had not, however, been adjusted to pH 4.5. During the 12 hr interval, the pH of a culture could decrease due to the formation of acid in the culture and could be as low as 2.9 - 3.0.

Prior to sampling, the pH of each culture was determined. The lower the pH the larger the volume of sample withdrawn. The replacement with fresh medium, pH unadjusted, caused the pH of a culture to rise (generally to pH 3.8-4.3). The pH was never allowed to rise above 4.5 and if necessary sulphuric acid solution was added to adjust the pH downwards.

The mycelium tended to attach itself to fermenter surfaces (metal and glass) and prior to sampling, the cultures were agitated at high speed for a short time to dislodge as much as possible of the attached growth. When attached growth became excessive, the culture was stopped, the fermenter cleaned and the culture started again.

Carbohydrate analyses were periodically performed on culture filtrates by initially the colorimetric procedure and subsequently by high pressure liquid chromotography. The cultures were also checked at regular intervals (microscopic examination-wet mounts) to ensure freedom from contaminants. One fermenter was operated without mechanical agitation i.e. as an airlift fermenter but without a draft tube. No detrimental effect was noted and subsequently all fermenters were operated in this "air lift" mode, with the stirrers only being used prior to sampling.

When sufficient Actinomycete biomass had been supplied for the uranium adsorption studies; the culture in one fermenter was continued (with sulphuric acid) for an additional period of two weeks. The pH was reduced to 2.3 with sulphuric acid solution. Aeration was continued to provide oxygen transfer and mixing. The culture was sampled (4L) after 7 days and sterile medium, pH 2.3, was added as make-up. The culture was stopped after a further 7 days and the biomass recovered. This biomass grown at pH 2.3 was treated as a separate biomass sample.

1.4.2. Acidophilic Rhizopus Species

The unicellular organism was cultured in the Microferm fermenters in a similar continuous-batch mode of operation as used with the Actinomycete cultures. Aeration and mechanical agitation were used and the sampling times were determined by monitoring the optical density of the cultures. The pH of the cultures was maintained at 4.5, however, and incubation was at low temperatures. Growth was poor and it was subsequently identified that the culture obtained from CANMET was in fact a contaminant. The culture was stopped.

1.4.3. Rhizopus arrhizus and Acidophilic Penicillium Species

Both of these organisms formed large, well developed pellets when cultivated in submerged culture with gentle agitation and aeration. However, in the Microferm fermenters pellets trapped at surfaces and metal fixtures tended to revert to fibrous growth (non-pelletized). In the continuous-batch mode of operation, sampling ports blocked within a few days.

Accordingly, production of both of these organisms was carried out in glass vessels without mechanical agitation but with the rate of aeration adjusted so as to create gentle "airlift" movement of the pellets within each culture. These were operated as batch cultures with harvesting occurring after 72-90 hrs.

1.5 HARVESTING OF BIOMASS

Immediately after sampling the cultures, the biomass was recovered from culture suspensions by filtration using either a high pressure filter (Nucleopore Corp.), with 0.45 micron pore size Tuffryn filters (Gelman) or vacuum filtration with 0.45 micron pore size mixed cellulose ester membrane filters (Millipore). The latter method was used with the pelletized Penicillium and Rhizopus biomasses whilst the former method was used with the more fibrous Actinomycete.

The biomass in each instance was rinsed twice with sterile, 1% (w/v) saline solution pH 3.5, and then stored at 4°C.

1.6 HEAT SHOCKING

Biomass material was inactivated by heating, with the exception of small amounts of biomass retained in the viable form for limited testing of the metal uptake capacity. The inactivation involved suspending the biomass in sterile saline solution (1% w/v) pH 3.5 and heating to 80 - 85°C for 20 minutes. The cooled biomass was recovered by filtration (Penicillium species and Rhizopus arrhizus) or by centrifugation at 15,000 rpm, for 10 minutes (Actinomycete). Inactivated biomass was stored at 4°C until required.

1.7 RESULTS AND DISCUSSION

1.7.1 The Organisms

The biomass from each stock culture received from Dr. McCready was examined microscopically (phase contrast) as wet mounts.

The neutrophilic Actinomycete had typical mycelial growth. The hyphae were not septate, but did display branching and spore production.

The Penicillium species had branching, septate hyphae with many single conidia observed that were not always terminally located.

The culture identified as the acidophilic Rhizopus organism was not considered typical. It appeared to be a bacterium and it displayed rods, sometimes in chains of 3-5 rods in length. Some cellular inclusions were very visible in the phase contrast microscope. It was subsequently identified that the culture supplied to Ontario Research was that of a contaminant organism which had infected all stock cultures at CANMET. Bulk culturing of this organism was not completed.

The R. arrihizus had the typical rhizopus mycelium and spore-production.

These observations were also noted for 24 hour cultures of the organisms in the broth at pH 4.5

1.7.2 Culture Conditions

Room temperature was found to be the preferred incubation temperature for cultures of the three Denison isolates. The optical densities of the cultures decreased significantly (visual observation) as the incubation temperature was raised to 27°C or then 32°C.

The Penicillium species and neutrophilic Actinomycete both grew at pH 2.3 (liquid and solid media) but the tests with the Rhizopus-like organism did not establish growth at pH 2.3. Biomass production was more rapid at pH 4.5 and this pH was therefore selected for the large-scale production of biomass samples. However, from the initial pH of 4.5, the cultures were allowed to decrease naturally to lower values.

1.7.3 Biomass Description

The Actinomycete grew in submerged culture as fibrous clumps but not as well pelletized as the Penicillium or R. arrhizus mycelia. As the Actinomycete cultures aged, pigments leached from the biomass into the culture supernatant producing a pink hue. However, this pigmentation did not appear to influence the production of biomass.

In spite of all precautions, occasional contamination was detected in one or two of the fermenters. The source of the contaminants, usually a yeast, is believed to be the laboratory air with the yeast entering the system as medium reservoirs were being replaced.

Contaminated cultures were stopped with new cultures initiated in their place as soon as the equipment had been cleaned and sterilized.

The age of the Actinomycete biomass appeared to influence the ease with which it could be recovered by filtration. Heat inactivation was observed to make the biomass more gelatinous and harder to recover by filtration.

The Penicillium species formed smaller (4-7 mm diameter) pellets than the R. arrhizus (10-15 mm diameter). The Penicillium pellets became much reduced in size as the entrapped water was removed by filtration. However, upon adding the water to the partially dried biomass, the pellets rapidly took up the water and swelled to their original size. Heat inactivation did not affect this behaviour. The Penicillium biomass appeared to be the most resilient.

The R. arrhizus pellets were large and fluffy. Upon filtration, the pellets "deflated" as the water was removed. Layers of biomass were deposited and the original pelletized form was not restored upon placing the mycelium in water. The layers of mycelium were very difficult to separate. Heat inactivation did not alter the appearance of the biomass.

The acidophilic Rhizopus organism behaved essentially like a bacterial culture i.e. no fibrous growth whatsoever.

During the recovery of biomasses, the plugging of filters was a constant problem, particularly with the Actinomycete and the R. arrhizus.

1.7.4 Conclusions

Based on the above observations, the Penicillium species is considered to have the most attractive physical attributes of the three biomasses produced in bulk. It is very resilient and disperses well in a dispersed reactor. The pellets are also sufficiently dense as to settle rapidly on standing.

1.8 COMMENTS ON BIOMASS PRODUCTION

Based on the respective culture conditions used in the study the typical productivities for the acidophilic Penicillium species and the Actinomycete were approximately 0.15 g dry solids/L/day and 0.60 g dry solids/L/day, respectively. The productivity of the R. arrhizus was not measured but, based on the yields of wet biomass, it was similar to that of the Penicillium species.

Biomass productivity and the cost of nutrients will influence significantly the economics of the process concept. However, at the present stage of development, the physical characteristics and the feasibility of reusing a biomass are viewed as more critical factors. The selection of the most cost efficient growth and the optimization of the culture conditions were not part of this study. As these latter aspects are optimized, it is envisaged that the impact of the production cost of the biomass on the process economics will be lessened.

The present study also did not attempt to identify which of the nutrients were limiting. In no instance was the glucose concentration an apparent limitation. However, in the case of the Actinomycete, it was demonstrated that the addition of tryptone (a protein hydrolysate) was most effective in enhancing productivity.

Future tests should assess the effects of nutrient concentrations on productivity and identify the most cost efficient industrial sources.

The airlift concept is recommended since it provides for efficient oxygen transfer with the fermentation broth and encourages the development of the pelletized form of growth in the case of the Penicillium species and R. arrhizus.

2. BIOSORPTION STUDIES

2.1 EXPERIMENTAL PROCEDURES

Batch adsorption and desorption studies were conducted in 250 ml ehrlenmeyer flasks using a Burrell wrist-action shaker maintained at a frequency of 300 Hz and an angular displacement of 5.5 degrees. For each test 100 ml of Denison minewater solution was used with varying biomass additions.

Biomass inactivated by heating to 80°C for 20 minutes was used for the majority of tests. However, batch adsorption rate tests were also conducted on a sample of viable material for two of the biomasses tested (Penicillium and Actinomycete).

Of the four biomasses identified for investigation in the program, the following were subjected to biosorption testing:

- acidophilic Penicillium
- neutrophilic Actinomycete
- Rhizopus arrhizus

Biosorption testwork was not conducted on the second Rhizopus species due to contamination which led to the inability to cultivate this organism. Details of these problems have been outlined in Section 1 of the Phase II report.

All tests were conducted on vacuum filtered biomass as-received, except in the case of Rhizopus. The Rhizopus as-received was in the form of large discs and thus required shredding with scissors to enable suitable dispersion.

2.1.1 Batch Adsorption Rate Tests

Batch adsorption rate testing was conducted using 0.5g (dry weight basis) biomass per 100 ml solution. Samples of 5 ml were taken at intervals of 5, 15, 30 and 60 minutes. These were filtered at 0.45 micron and submitted for assay. After 120 minutes the shaker was stopped and the entire biomass/solution mixture was filtered at 0.45 micron. The solution was then submitted for uranium and yttrium analyses.

During the initial stages of the program all the variables outlined in Phase I were investigated for each of the biomasses. However, as the tests proceeded it became apparent that loading at pH values below 3 was very poor. Thus, the low pH investigations were not conducted during the later stages of the program.

An outline of the batch rate tests studied is given in Table 1.

The standard solution used was Denison minewater, a complete analysis of which is given in Table 2. Testing at 12°C was conducted using a constant temperature water bath. NaOH was used for pH adjustment. The following were used for the added ion tests:

$Fe_2(SO_4)_3$ for the high Fe^{3+} tests
Na_2SO_4 for the high $SO_4^{=}$ tests
Na_3PO_4 for the high PO_4^{3-} tests
$CaCl_2$ for the high Ca^{2+} tests

The tests with added organic carbon were conducted by adding a mixture of a 2:1, fuel oil: axel grease in a ratio of 0.2g per 100 ml Denison minewater.

Acid washed Denison mill tailings were added to the minewater at a concentration of 100 ppM for the high TSS tests.

The uranium and yttrium loadings on the biomasses were calculated from the initial and final solution assays.

2.1.2 Batch Equilibrium Adsorption Tests

The equilibrium adsorption tests were conducted in the same manner as the rate tests. However, three additions of biomass (0.1, 1.0 and 2.0g dry weight basis) per 100 ml of solution were employed. Each test was allowed to run for 120 minutes, at which time the mixture was filtered at 0.45 micron and the solution was submitted for assay.

The variables studied for the batch equilibrium adsorption tests are the same as those used for the rate tests (section 2.1.1) and are summarized in Table 1. All tests were conducted using inactivated biomass.

2.1.3 Batch Desorption Rate Tests

Batch desorption studies were conducted on each biomass loaded for 2 hours under the optimum conditions as determined by the batch adsorption tests. Desorption was conducted using three solutions; NaCl, H_2SO_4 and Na_2CO_3. Initially, the tests were conducted at 0.1 and 0.02 N strengths. However, poor results at 0.02 N precluded further testing at this concentration.

The desorption rate tests were performed in the same manner as the adsorption rate tests, using the solutions described above. Samples were taken at 5, 15, 30 and 60 minute intervals, with the entire mixture being filtered after 120 minutes. The amount of uranium desorbed from the biomass was determined from the solution assays.

2.1.4 Equilibrium Desorption Tests

Equilibrium desorption tests were conducted on the loaded biomasses to estimate the maximum desorption and create equilibrium curves. The tests were performed in the same manner as the equilibrium loading tests. Biomasses loaded under optimum conditions were used. The desorbing solutions were the same as those outlined for the desorption rate tests (section 2.1.3).

2.1.5 Continuous Actinomycete Shaker Tests

Continuous shaker tests were conducted on the Actinomycete in lieu of column tests, due to the inability to obtain suitable flowrates through this biomass in the standard column apparatus.

In total, two adsorption/desorption cycles were conducted. The tests were performed in duplicate with one of the samples rinsed with EDTA prior to the re-adsorption cycle.

Adsorption was conducted by contacting 1.0g dry weight basis Actinomycete with 100 ml of pH 4.0 minewater. After 2 hours shaking, the mixture was centrifuged and the solution was sampled for U assay. The biomass was then contacted with another 100 ml of fresh minewater for 2 hours. This procedure was continued until no uranium was loaded from solution.

The procedure for desorption testing was similar to that outlined above. However, only 50 ml of eluant was used and the test duration was only 15 minutes. These tests were continued until no uranium was detected in the eluate. The eluant used for both samples was 0.1 N Na_2CO_3.

EDTA treatment was performed on one of the Actinomycete samples prior to re-adsorption. The procedure here was similar to that outlined for the desorption above, however only 4 cycles were performed. 0.02 M EDTA disodium salt solution was used for these tests.

The biomasses were rinsed with distilled water between adsorption and desorption (or between adsorption and EDTA) tests.

2.1.6 Column Tests

Column tests were conducted on both *Penicillium* and *R. arrhizus*. Four adsorption/elution cycles were conducted on *Penicillium*. In the final cycle the use of EDTA prior to re-adsorption was investigated. Three cycles were conducted on the *Rhizopus* species with the use of EDTA investigated prior to the final adsorption cycle.

The column studies were conducted in a 1.5 cm ID burette with a constant head tank feed inlet. The biomass was placed into the column within layers of glass wool and demineralized sand to prevent the escape of cells. The solution flowrate was maintained by adjusting the outlet stopcock position.

For these tests, pH 4.0 Denison minewater was used for adsorption and 0.1 N Na_2CO_3 was used as the eluant. The flowrates for these two solutions were maintained at approx. 6 BV/hr. and 3 BV/hr., respectively, for *Penicillium*, and 8 BV/hr. and 2.5 BV/hr., respectively, for the *Rhizopus*.

Solution samples were collected at timed intervals for uranium analysis.

All adsorption and desorption cycles were conducted until no further evidence of any reaction was noted from the solution assays.

Between all adsorption and desorption cycles 100 ml of distilled water was run through the columns and analyzed for uranium.

The EDTA cycle was conducted to determine the regenerative properties of this chemical on the biomasses. After desorbing with Na_2CO_3, 0.02 M disodium EDTA salt was run through the system at the same rate as the eluant for a total of approx. 5 bed volumes. Periodical samples of the spent EDTA were taken for uranium assay.

2.2 RESULTS AND DISCUSSION

All raw data for the tests outlined in Section 2.1 are available in the Appendix. The results are summarized and discussed in the following sections.

2.2.1 Batch Adsorption Tests
Rate Tests

Loading rate curves for Actinomycete are shown in Figures 1 through 8. Curves for Penicillium are shown in Figures 9 through 15. The Rhizopus plots are given in Figures 16 and 17. It should be noted that not all the tests conducted are represented by the loading curves. This is because no significant uranium or yttrium loading was observed for a number of conditions studied. This was particularly the case for Actinomycete at pH 2 (natural pH of the minewater). Although both Penicillium and Rhizopus performed better than Actinomycete under these conditions (Figures 2, 9 and 16), all biomasses exhibited uranium loadings below 5 mg U per g dry weight biomass.

At higher pH values all species experienced a significant increase in uranium loading (Figures 3 and 4 for Actinomycete, Figures 13 and 14 for Penicillium, and Figure 17 for Rhizopus) with very good results obtained at pH 4. This may be due to either an increase in biomass activity at the higher pH or due to the reduction of iron content in the solution from precipitation.

The rate curves indicate that Penicillium has both the highest loading capacity and the fastest adsorption rate of three biomasses tested. However, from the data it appears that none of the biomasses reach equilibrium within two hours at pH 4.

A ranking of the biomasses in terms of adsorption capacity at pH 4 is as follows:

#1 Penicillium
#2 Rhizopus
#3 Actinomycete

A ranking of the biomasses in terms of adsorption rate at pH 4 is:

#1 Penicillium
#2 Actinomycete
#3 Rhizopus

One loading test was conducted using Denison minewater as received and Actinomycete grown at pH 2.3 (the other Actinomycete was grown at a pH of about 4). However, the results showed no uranium or yttrium loading and thus have not been plotted. This indicates that the pH of the growth medium has no effect on the performance of the biomass under the conditions studied.

Tests with added ions, high TOC, high TSS and low temperatures (Penicillium and Actinomycete only) show a decrease in uranium loading from the standard tests for both biomasses. In a number of cases, no significant uranium loading was noted, thus no rate curves could be plotted. The results under the varied conditions cannot be accurately quantified due to the low adsorption capacity of both biomasses at pH 2. Variation in biomass loadings at the low values as noted here may be due more to variation in the solution uranium content than to biomass performance. A comparison of the various tests at this low pH would thus not be accurate nor representative.

Tests conducted using viable biomass (Figures 2 and 10) indicate that heat inactivating improves uranium uptake. This was particularly the case for Penicillium, where the capacity was greatly increased by inactivation (Figure 9 compared to Figure 10).

A test was conducted using "younger" inactivated Actinomycete in Denison minewater as-received. No uranium or yttrium loading was achieved, thus the results could not be plotted. This indicates that biomass age may not have significant effect on uranium adsorption.

Yttrium loading throughout the test program was found to be very poor. In all cases little or no yttrium loading was detected. Increasing the pH of the solution did not result in an increase in yttrium adsorption.

Equilibrium Tests

The equilibrium loading curves for Actinomycete are shown in Figures 18 through 22. Curves for Penicillium are shown in Figures 23 through 26. For Rhizopus, only the test conducted at pH 4.0 produced meaningful results. This loading curve is shown in Figure 27.

In most cases, the data obtained from the equilibrium loading tests were too inconsistent and scattered to give meaningful relationships between solution content and biomass loading.

This was particularly the case for the tests conducted at pH 2.0, where uranium loading was minimal. In fact, a number of the equilibrium curves shown here (Figures 18, 19, 20 and 22) are not particularly useful due to their inconsistency and limited range.

Considering the above comments, a limited number of conclusions can be drawn from the equilibrium adsorption studies. These are summarized as follows:

- maximum uranium loadings for all three biomasses were obtained using minewater adjusted to pH 4.0[1]. Actinomycete and Penicillium both loaded to about 21 mg U per dry g biomass. The Rhizopus loadings obtained in this study were only about 10 mg U per g biomass. The results for Rhizopus were found to be variable. Later tests (conducted for desorption studies) showed loadings of up to 25 mg U/g biomass. On average, Rhizopus loading

1 The test conducted at pH 3.0 on Penicillium has been disregarded due to inconsistency.

was between 10 and 15 mg U/g biomass. This variability in results could be due to either differences in biomass particle size or to differences in production variables.

- maximum loading for Actinomycete and Penicillium using minewater as-received (pH 2.0) was 2.7 mg U per g biomass and 12 mg U per g biomass, respectively. Penicillium loaded much higher than Actinomycete under the standard conditions. The Rhizopus loading results were inconsistent and thus no comparison for this species can be made.

- In all cases, increasing the pH of the minewater resulted in increased uranium loading.

- Yttrium loading curves have not been developed because each of the biomasses studied did not suitably load this species.

2.2.2 Batch Desorption Tests

Rate Tests

Desorption rate curves for Actinomycete are shown in Figures 28 and 29. Although the tests were conducted using all three desorbants at two concentrations each, only three tests resulted in sufficient uranium removal to facilitate the development of rate curves. These were 0.1 N Na_2CO_3, 0.02 N Na_2CO_3 and 0.1 N H_2SO_4. The biomass used for these tests was loaded to 4.025 mg/g uranium.

Of the desorbants, Na_2CO_3 performed the best particularly at 0.1 N concentration. At this level, approximately 90% of the uranium was desorbed from the biomass during the first five minutes of the test.

H_2SO_4 exhibited only marginal desorbing properties for Actinomycete, with initial uranium removal followed by partial re-adsorption with time. NaCl did not show any significant capacity to elute uranium from this biomass.

The Penicillium desorption rate curves are shown in Figures 30 through 32. The raw data for these tests is given in the appendix. Three tests were conducted. These are:

0.1 N Na_2CO_3
0.1 N H_2SO_4
0.1 N NaCl

Biomass for these tests was loaded to 13 mg U/g biomass (Na_2CO_3 and H_2SO_4 tests) and 16.4 mg U/g (NaCl test).

A ranking of the performance of the three desorbants as applied to Penicillium is as follows:

1 - Na_2CO_3
2 - NaCl
3 - H_2SO_4

For the Na_2CO_3 test, almost complete desorption was affected on the Penicillium within the first five minutes of the run. For H_2SO_4, initially the rate of desorption from this biomass was fast, however it levelled off after 30 minutes with only about 68% uranium elution. The NaCl desorption rate was slower, but after two hours practically 100% removal was achieved.

Desorption rate curves for Rhizopus are shown in Figures 33 and 34. Biomass for these tests was loaded to 25 mg/g (Na_2CO_3 and H_2SO_4 tests) and 13.7 mg/g (NaCl test).

Of the three eluants tested, 0.1N Na_2CO_3 performed the best (36% desorbed). NaCl was found to be particularly ineffective for Rhizopus desorption. In all cases, desorption was not as rapid as with Penicillium and Actinomycete.

Of the three biomasses tested, the Penicillium showed the most rapid and complete desorption characteristics. Although the Actinomycete showed almost 100% uranium elution after two hours, the rate was slower than for Penicillium. Rhizopus, on the other hand, showed very slow elution properties and low capacities (36% maximum desorption).

Equilibrium Tests

Equilibrium desorption tests were conducted on all three biomasses. However, all the curves for the tests are not shown. This is because for a number of tests either very high or very low uranium desorption gave inconclusive results which could not be plotted. The raw data for all the tests conducted is presented in the Appendix.

The equilibrium curves for the Actinomycete are shown in Figures 35 and 36. Biomass for these tests was loaded to 4.025 mg U/g. Plots have been made of the 0.1N Na_2CO_3, 0.02N Na_2CO_3 and 0.1N H_2SO_4. The figures for Na_2CO_3 are inconclusive, however, due to the very high amount of uranium desorption, particularly in the case of the 0.1N solution. Desorption with H_2SO_4 was not very efficient, as previously observed during the desorption rate tests.

The Penicillium equilibrium desorption curves are given in Figures 37 and 38. Biomass for these tests was loaded using pH 4.0 minewater to 16 mg/g for the Na_2CO_3 test and 12 mg/g for the H_2SO_4 test. The equilibrium curves once again show that 0.1N Na_2CO_3 is the most effective eluant. NaCl was found to be very ineffective on this biomass and the equilibrium curve has therefore not been plotted. Desorption with H_2SO_4 was found to be moderately effective during the equilibrium testing, with a maximum elution of 72.5% uranium (Figure 38).

Equilibrium desorption curves for Rhizopus are shown in Figure 39. Plots of the 0.1N H_2SO_4 and 0.1N Na_2CO_3 have been made. The test using 0.1N NaCl showed very poor elution results and thus could not be plotted. Biomass for these tests was loaded to 25 mg U/g using pH 4.0 minewater. The results shown in Figure 39 indicate Na_2CO_3 to be a more effective eluant than H_2SO_4 for Rhizopus. The results also show that elution of uranium from the Rhizopus species is much less effective compared to the Penicillium or Actinomycete.

2.2.3 Actinomycete Continuous Tests

Due to the lack of sufficient solution flow through a packed bed column of the Actinomycete, continuous adsorption and desorption testing was conducted using the Burrell wrist-action shaker device as described previously.

Two tests were conducted in duplicate to facilitate the study of EDTA for use as a regenerative agent.

Prior to testing, a sample of the Actinomycete was wet screened to determine the size distribution. This is given in Table 3.

Two complete adsorption/desorption cycles were conducted on the biomass. Loading and elution curves for all tests are given in Figures 40 through 43. EDTA testing was conducted on the sample #1 material. A summary of the uranium balance for the investigation is given in Table 4.

As can be seen from the results, both samples performed almost identically throughout the study. However, the EDTA sample was found to re-adsorb slightly better than the non-EDTA material (Figure 42).

Two dramatic differences were observed in the Actinomycete performance between the continuous and batch tests. Firstly, the biomass adsorption capacity was much higher in the continuous tests; 62.5 mg/g loading compared to about 21 mg/g in the batch studies.

Secondly, desorption during the continuous tests was very poor (only about 40% elution of the adsorbed uranium). Almost complete elution of uranium was obtained using 0.1N Na_2CO_3 during batch testing. A possible explanation for this phenomenon is the accumulation of uranium on to the biomass during extended periods of loading in a form which is not readily eluted.

The inefficient elution of uranium resulted in poor re-adsorption performance. During the second adsorption cycle, uranium loading was only about 30% of the first cycle capacity.

Yttrium was not followed in the study due to the lack of adsorption of this species during batch tests.

An accurate size distribution of the Actinomycete after shaking could not be determined due to the loss of fine material while decanting during the study.

2.2.4 Column Tests

Penicillium

Four complete adsorption/desorption cycles were conducted on Penicillium. The loading and elution curves are shown in Figures 44 through 50. A summary of the uranium balance for the study is given in Table 5. The EDTA wash was conducted directly after Cycle 3 desorption and before Cycle 4 adsorption.

Initially, the Penicillium loading was similar to that obtained during batch testing (22.5 mg U/g biomass). However, after repeated cycles the quantity of uranium on the biomass was built up so that after the third cycle the capacity was up to 36.1 mg/g. Net uranium loading, though, steadily decreased with repeated use. During the third cycle only 15.2 mg/g uranium was adsorbed, compared to the initial 22.5 mg/g. This is probably due more to the inefficiencies in desorption rather than to adsorption limitations.

Penicillium desorption performance was very poor in the column tests. Initially, only 44.3% of the loaded uranium was removed. This fell to 13.6% after four cycles. This phenomenon is probably due to the uptake of uranium in a form not readily leachable. Similar observations were made for Actinomycete during continuous testing.

EDTA was not found to regenerate Penicillium (see Figure 49). In fact, uranium adsorption actually decreased after EDTA washing. Cycle 3 adsorption was 15.2 mg/g while cycle 4 adsorption (after EDTA) was only 13.0 mg/g. This decrease is most likely not due to the detrimental effect of EDTA but rather to the loss in biomass efficiency with repeated use.

Size distributions for the Penicillium were determined both before and after column testing to study attrition effects. A summary of the results is given in Table 6. The results show a distinct attritioning effect of column loading/desorption on the biomass.

The cumulative percent passing 14 mesh was increased from 3.7% before column testing to 20.8% after; an increase of over 5 1/2 times. However, no accumulation of fine material (ie: less than 65 mesh) was noted after repeated loading and elution, thus indicating minimal biomass losses due to attrition.

Rhizopus

Three adsorption/desorption cycles were conducted on the Rhizopus species. The conditions used for these tests were maintained as near as possible to those employed for Penicillium to enable accurate comparisons. The loading and elution curves for the investigation are shown in Figures 51 through 56. A summary of the uranium balance is given in Table 7.

In general, the Rhizopus column adsorption performance was poor compared with that of the Penicillium or Actinomycete. Maximum loading was only 19.9 mg U/g biomass (adsorption cycle #2). These poor loading results are similar to those obtained for the Rhizopus species during batch adsorption testing.

Rhizopus desorption performance was substantially better in the column than in batch tests. In addition, Rhizopus column desorption was much better than that for the Penicillium and Actinomycete. During the first two cycles 100% desorption was achieved in as low as 11 bed volumes of eluant, creating a highly concentrated solution. Only 95% elution was achieved in cycle 3, thus indicating a decrease in desorption efficiency with time. EDTA was not found to enhance adsorption as indicated by the cycle 3 results.

Size distributions for Rhizopus were not determined, as the size of the biomass particles for this species is arbitrary, depending on the thoroughness of shredding prior to use.

Table 1
Uranium Biosorption Variables Tested

	pH			Temperature		Contaminent Effects					
Biomass	2.0	3.0	4.0	Room (22°)	12°C	Fe^{3+}	SO_4^{2-}	PO_4^{3-}	Ca^{2+}	TOC	TSS
Actinomycete											
inactivated	X	X	X	X	X	X	X	X	X	X	X
viable	X										
Penicillium											
inactivated	X	X	X	X	X	X	X	X	X	X	X
viable	X										
R. arrhizus											
inactivated	X		X								
viable											

Table 2

Head Analysis of Denison Minewater

ELEMENT	CONCENTRATION mg/l	ELEMENT	CONCENTRATION mg/l
Co	3.8	Pb	<0.02
Zn	2.3	Ni	2.0
Cd	0.02	Cr	0.11
B	0.44	Na	9.0
Bi	0.16	Th	71
P	8.5	Y	10
Be	0.005	As	0.84
Si	17	U	90
Fe	1380	SO_4^{2-}	5400
Mn	0.88	TSS	6
Ca	101	Cl^-	18
Mg	5.3	Fe^{2+}	19
Cu	2.2	TOC	6.2
Al	28	NO_3^-	92
V	<0.01	Fe^{3+}	1361
Mo	<0.05	PO_4^{3-}	26

FIGURE 1

INACTIVATED ACTINOMYCETE

LOADING RATE

STD. CONDITIONS →

24 C

pH - 2.10

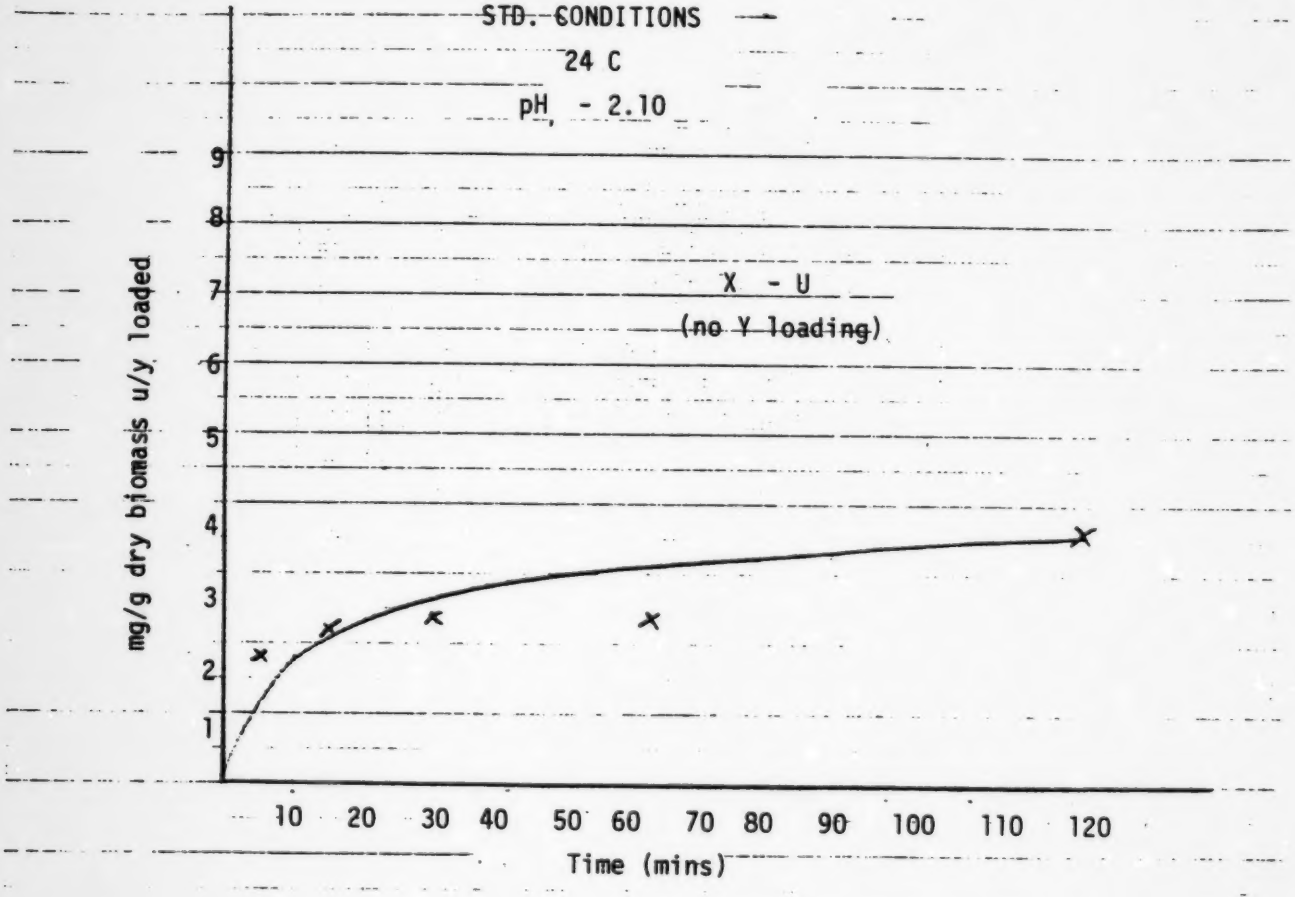


Figure 2

Live Actinomycete Loading Rate

24°C

pH = 2.10

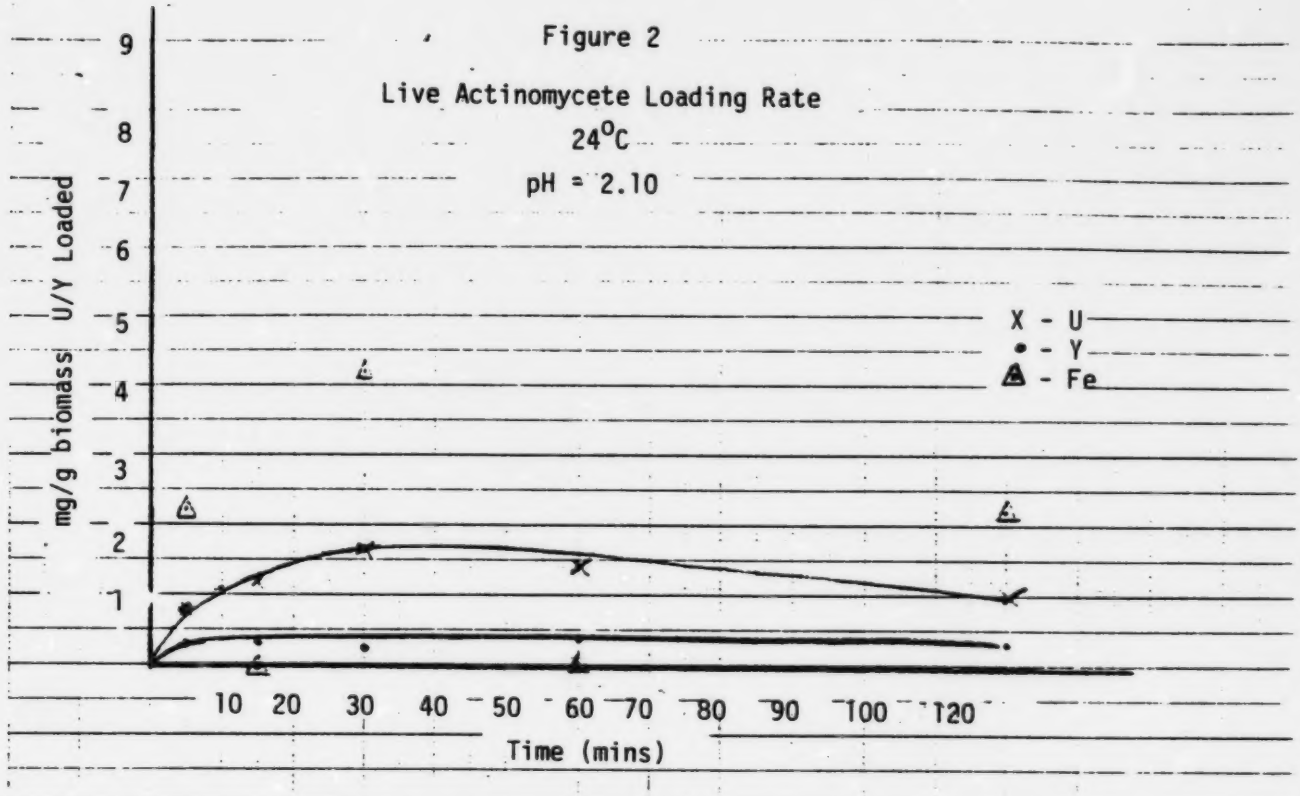


Figure 3

Inactivated Actinomycete Loading Rate

pH -2.95

24°C

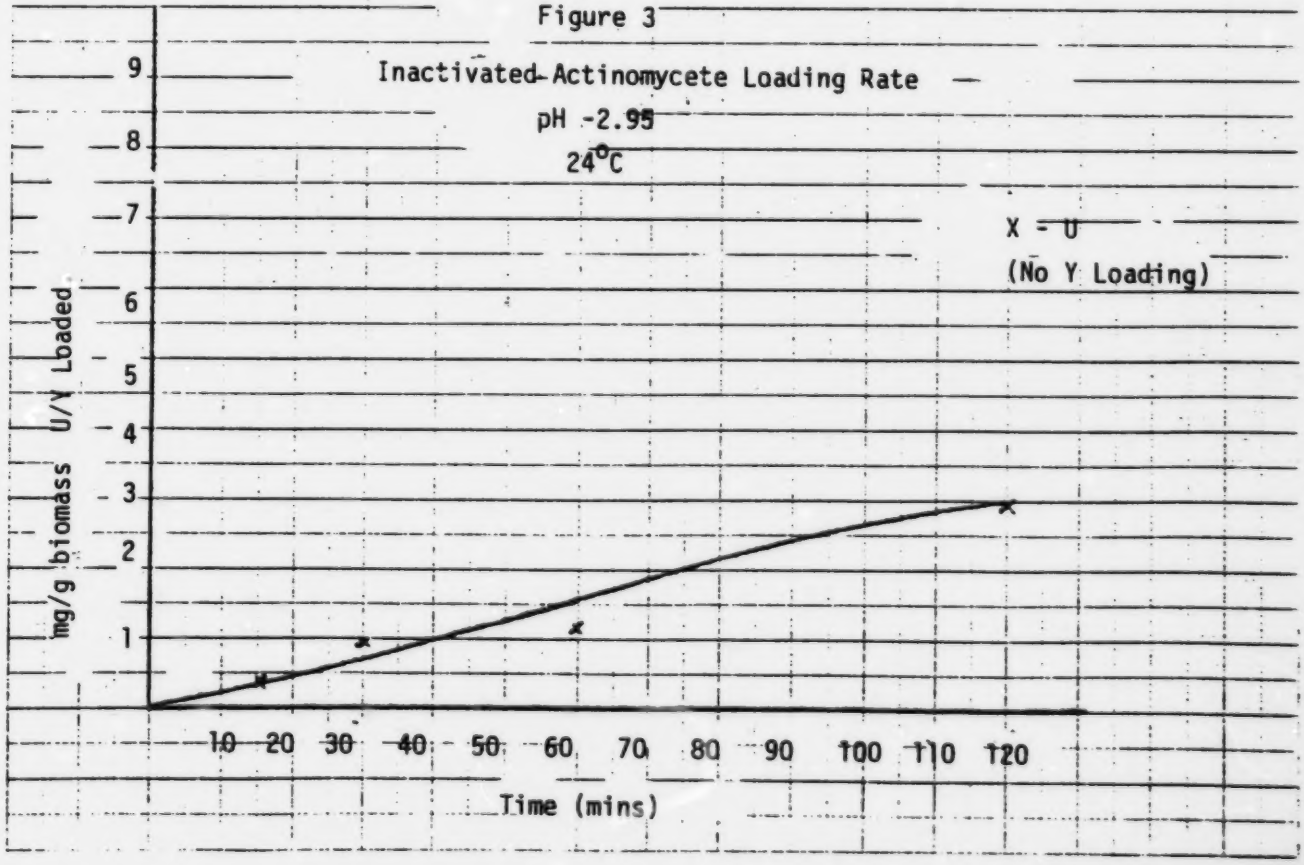


Figure 4

Inactivated Actinomycete Loading Rate

24°C

pH - 4.25

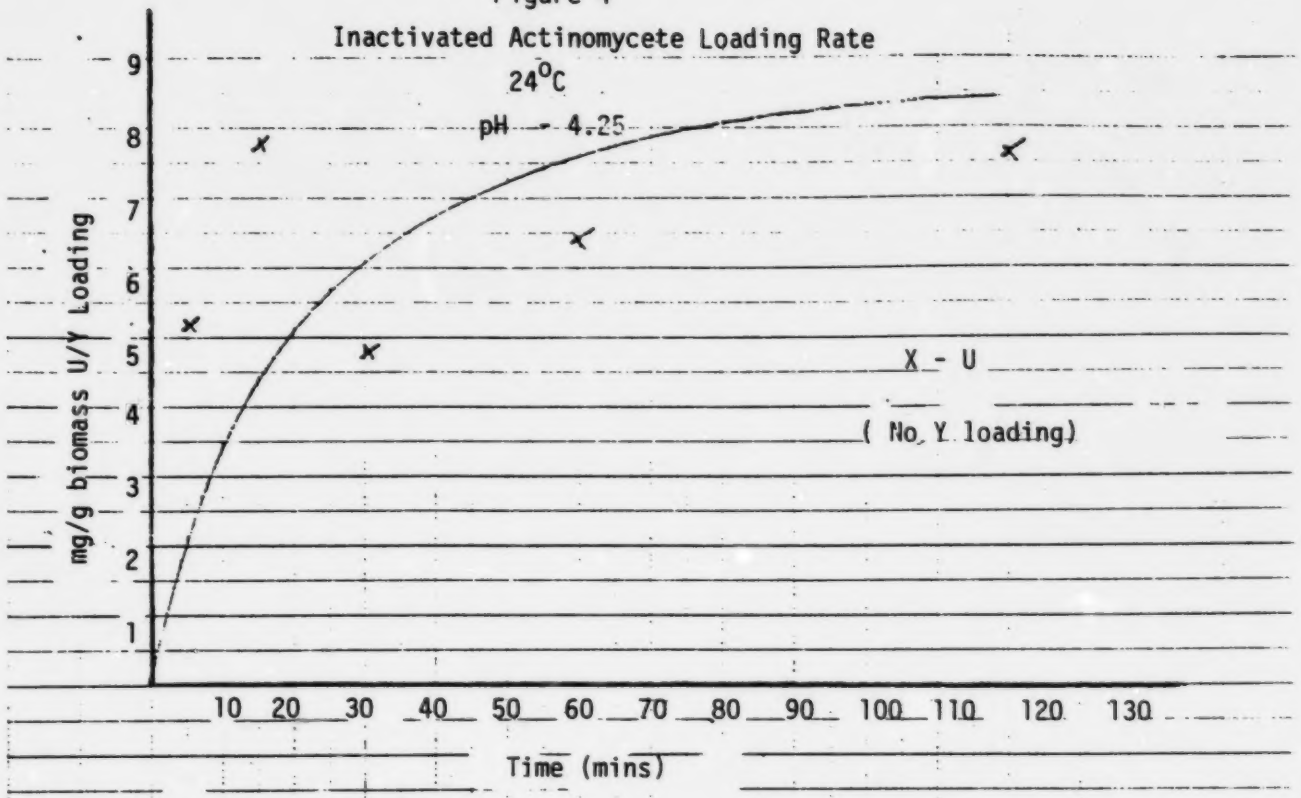


Figure 5

Inact. Actinomycetes Loading Rate

pH - 1.75 High Fe^3

24°C (5210 mg/l)

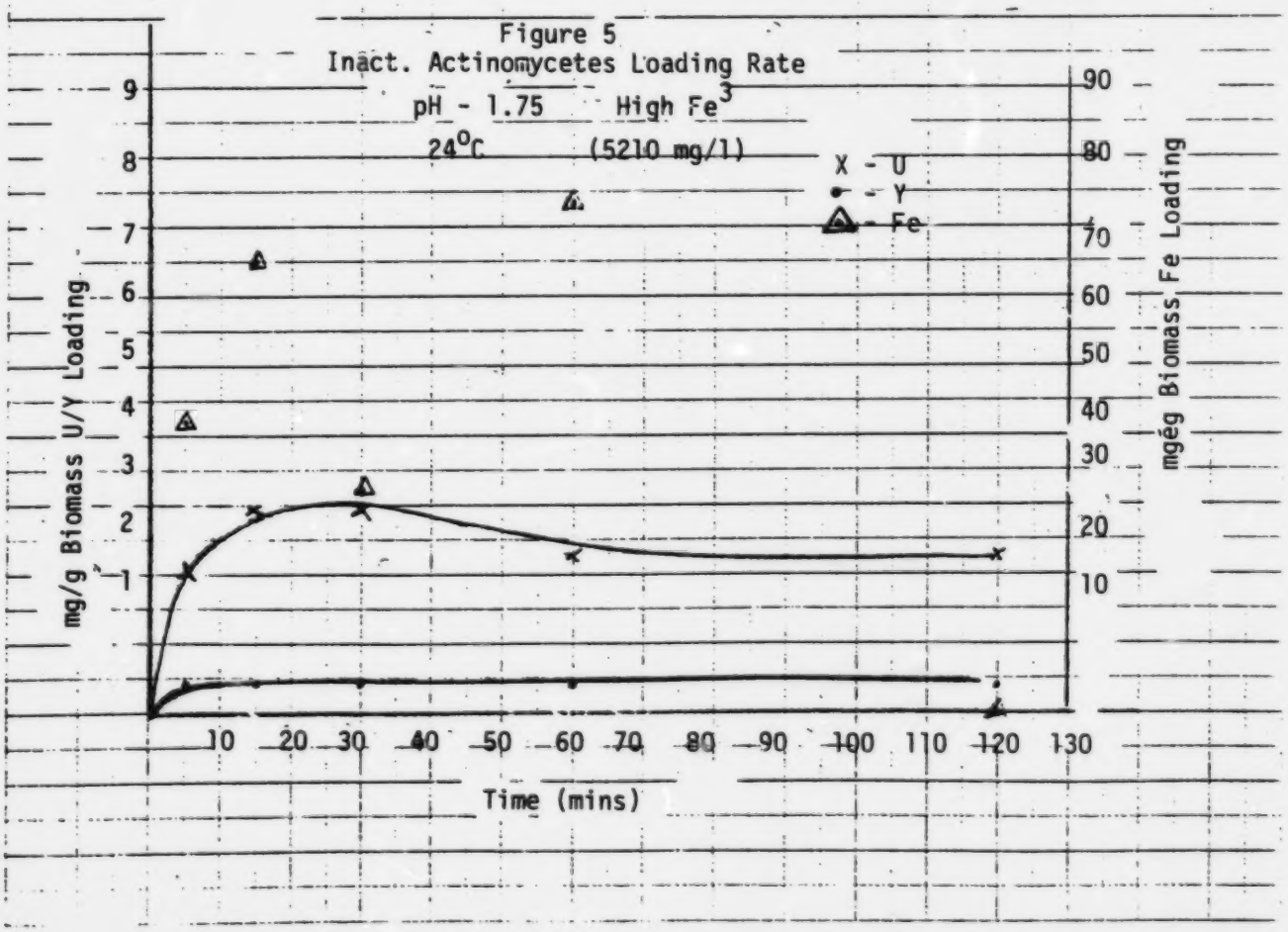


Figure 6

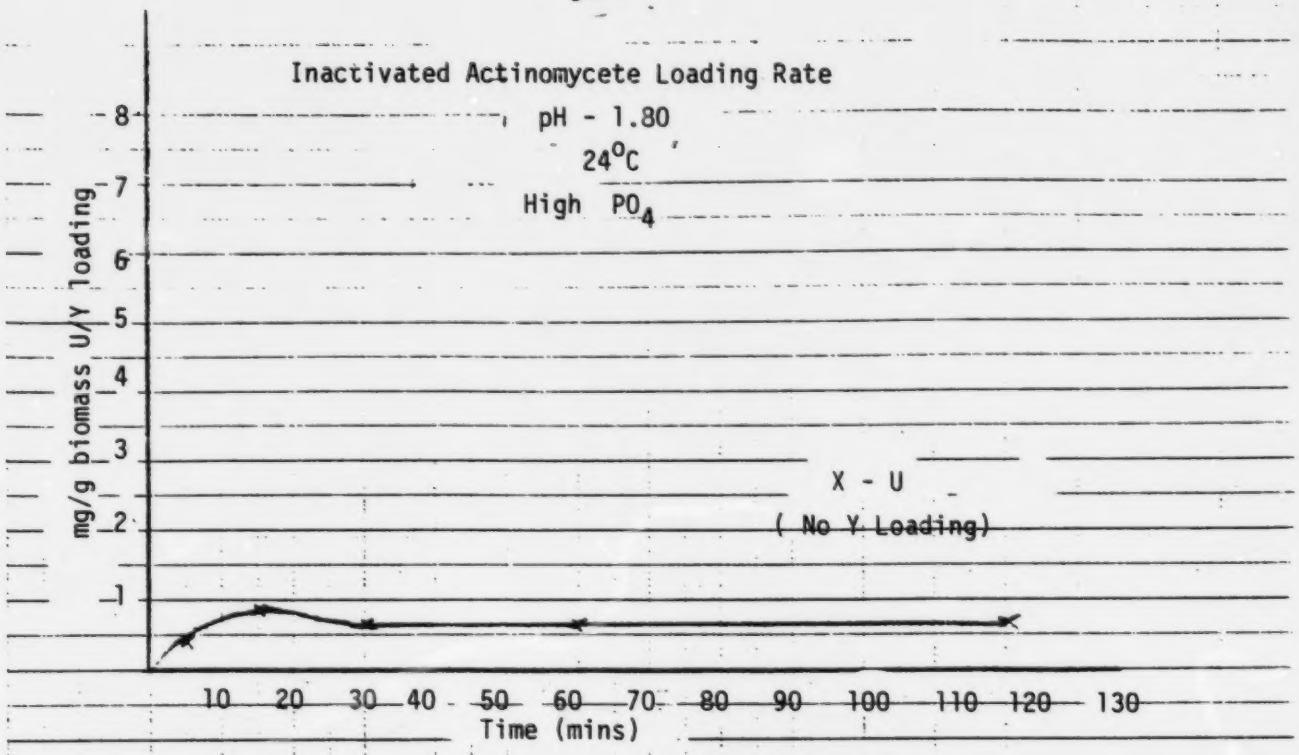


Figure 7

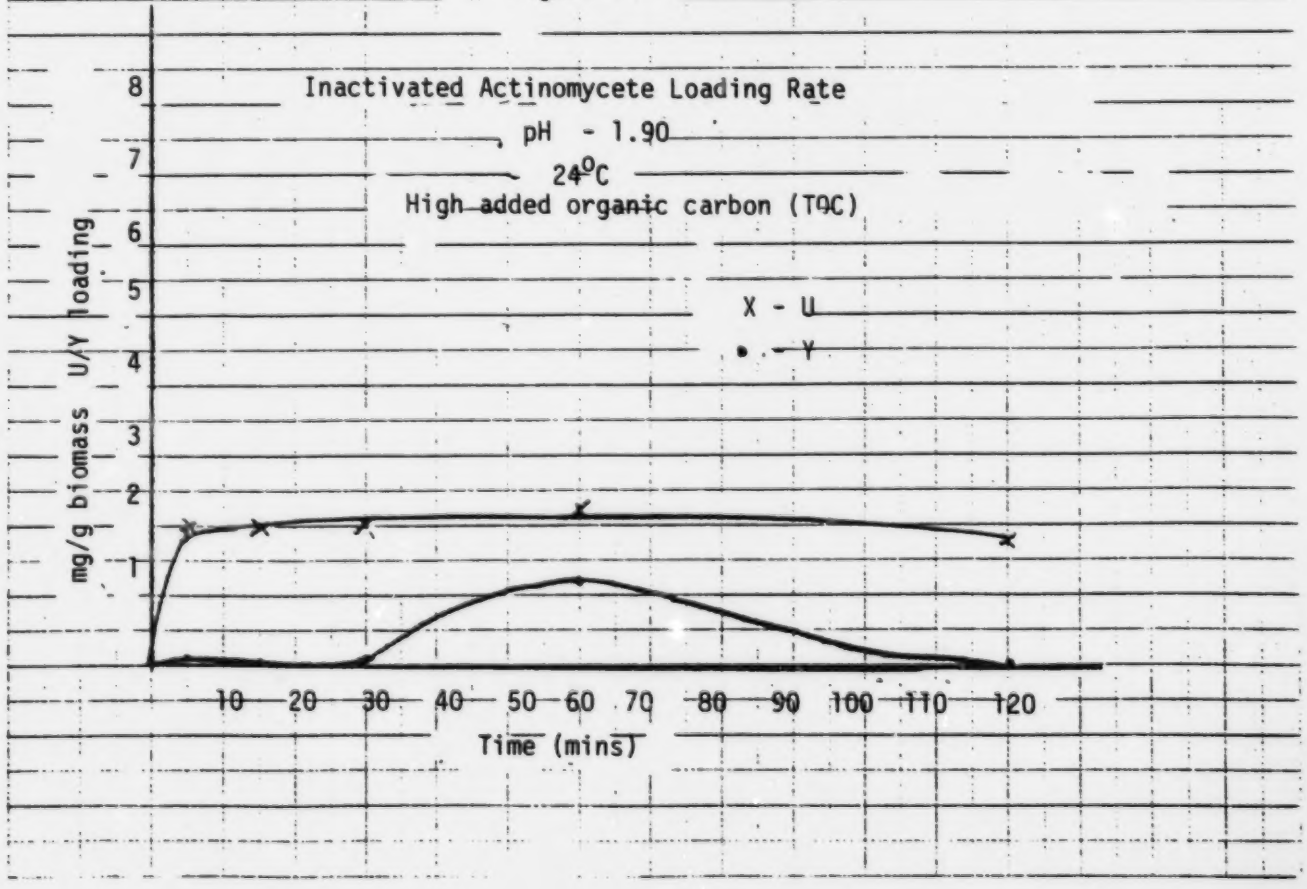


Figure 8

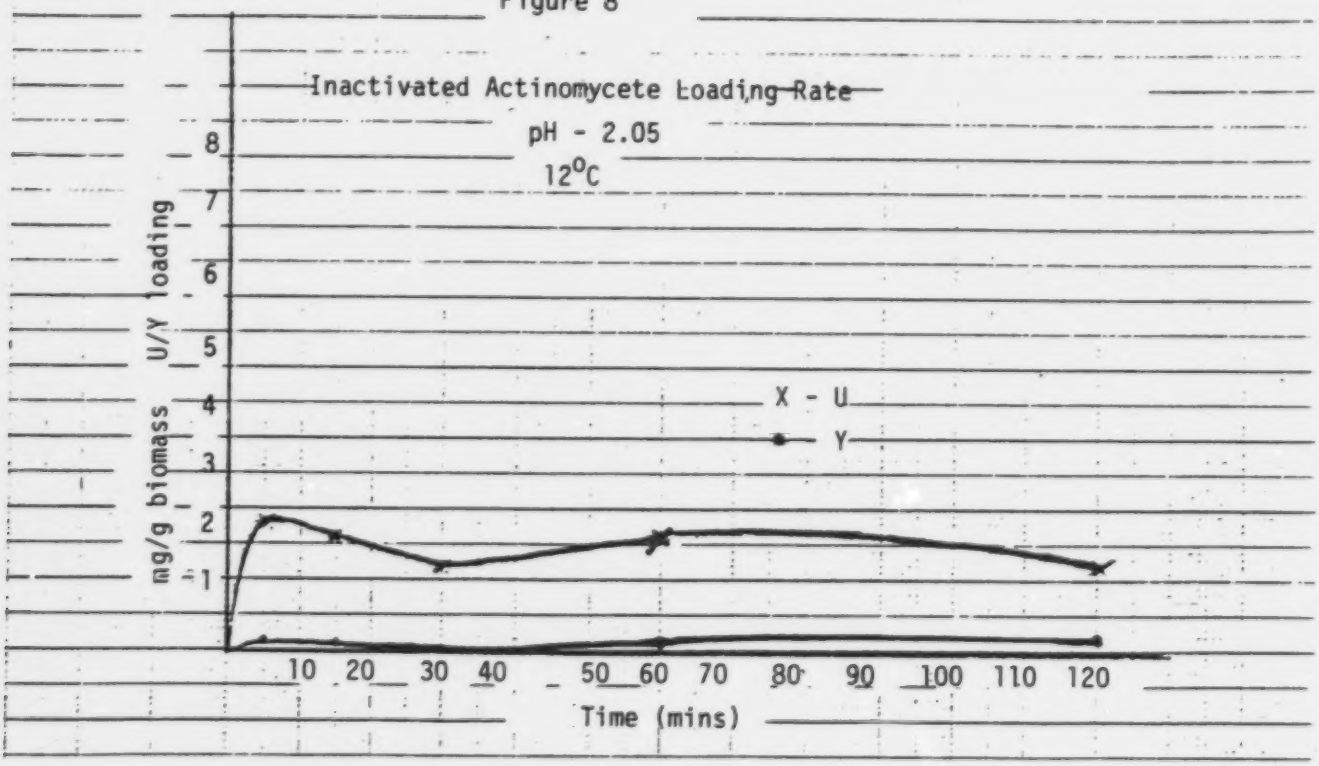

Inactivated Actinomycete Loading Rate
pH - 2.05
12°C
mg/g biomass U/Y loading
8
7
6
5
4
3
2
1
X - U
Y
10 20 30 40 50 60 70 80 90 100 110 120
Time (mins)

Figure 9

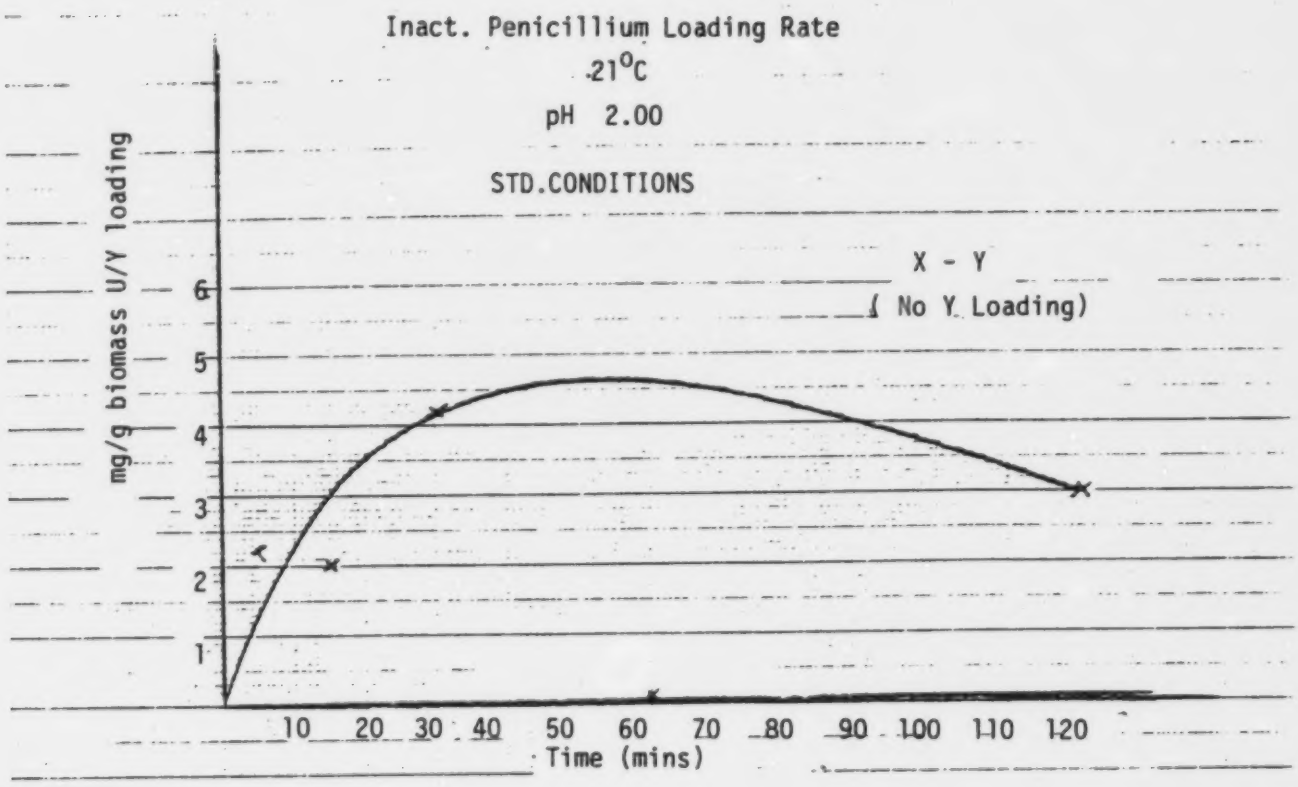


Figure 10

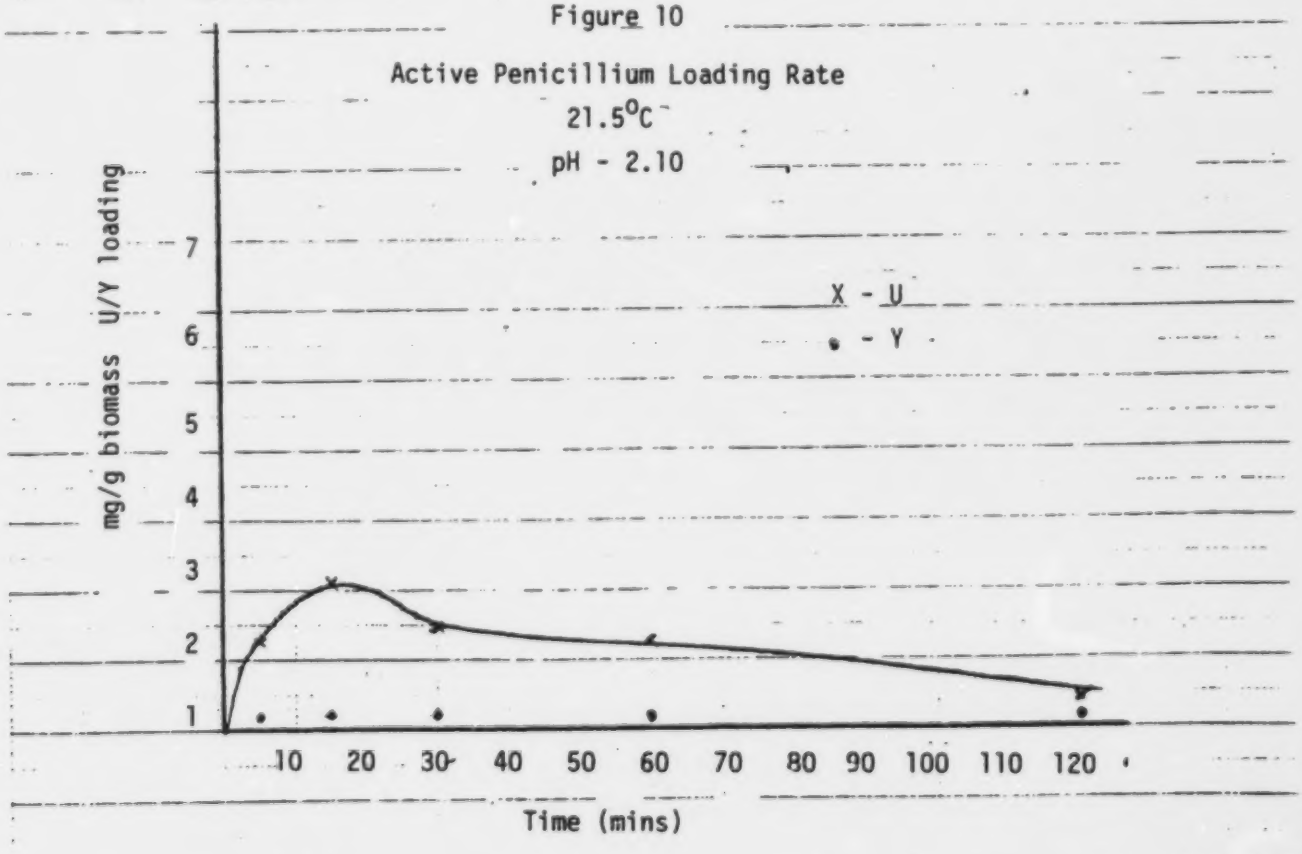


Figure 11

Inact. Penicillium Loading Rate

22°C

pH 2.00

High Fe^{3+}

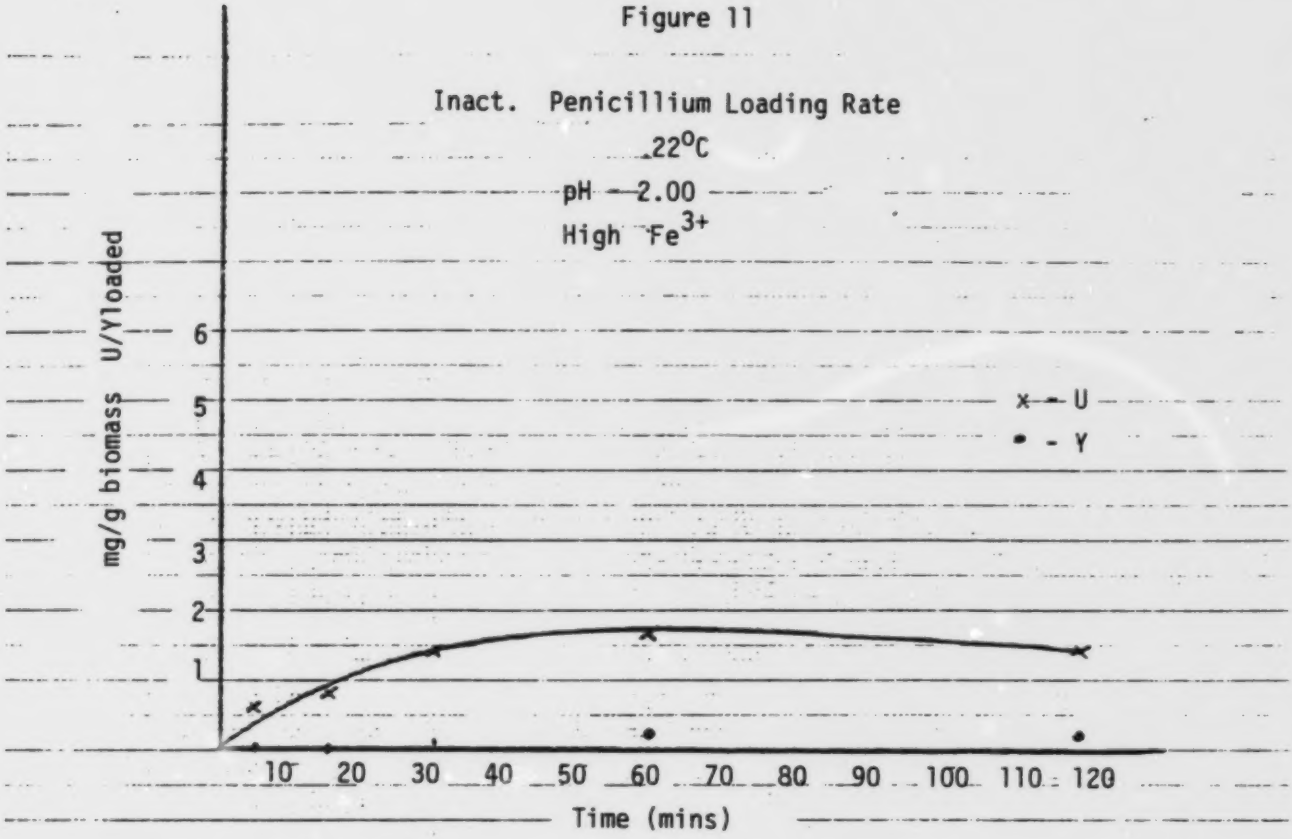


Figure 12

Inact. Penicillium Loading Rate

12°C

pH 2.10

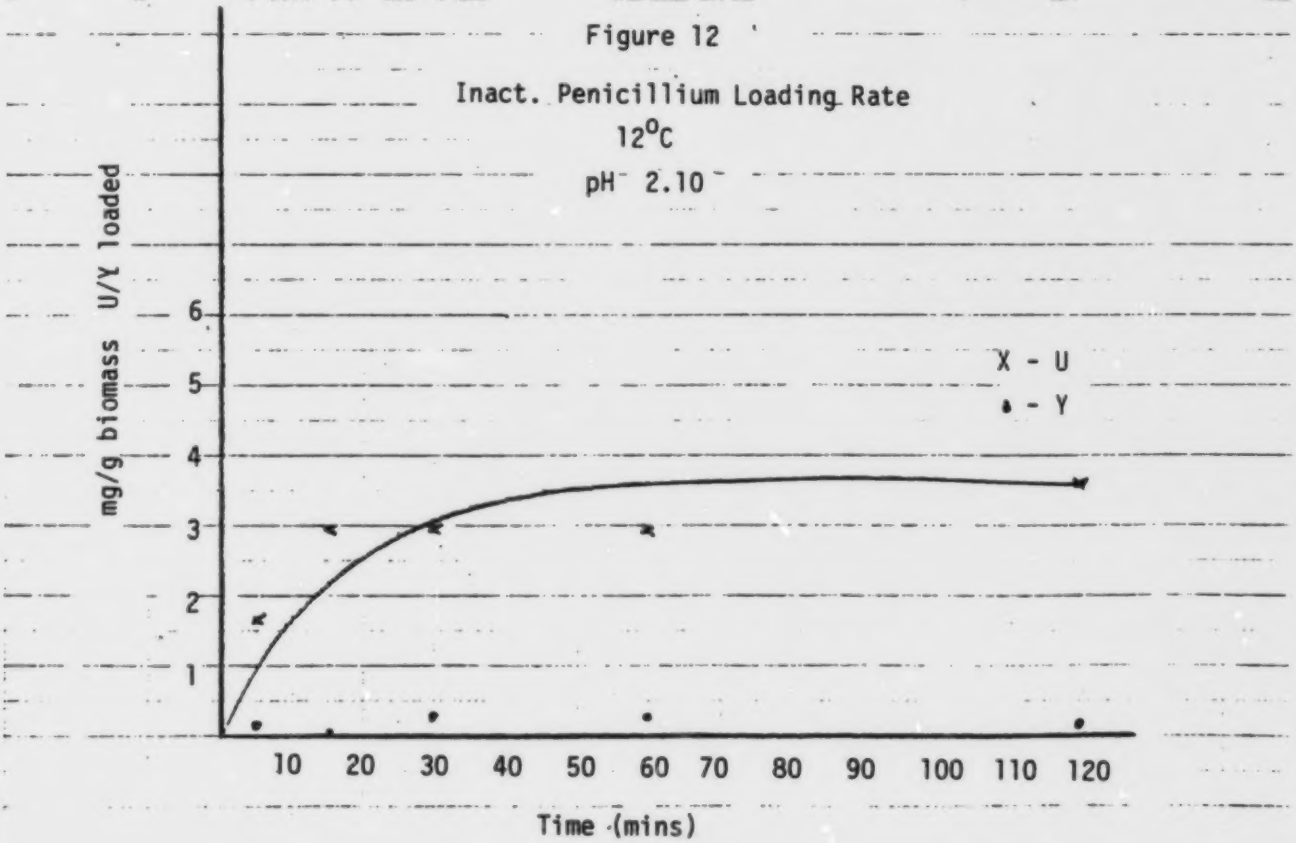


Figure 13

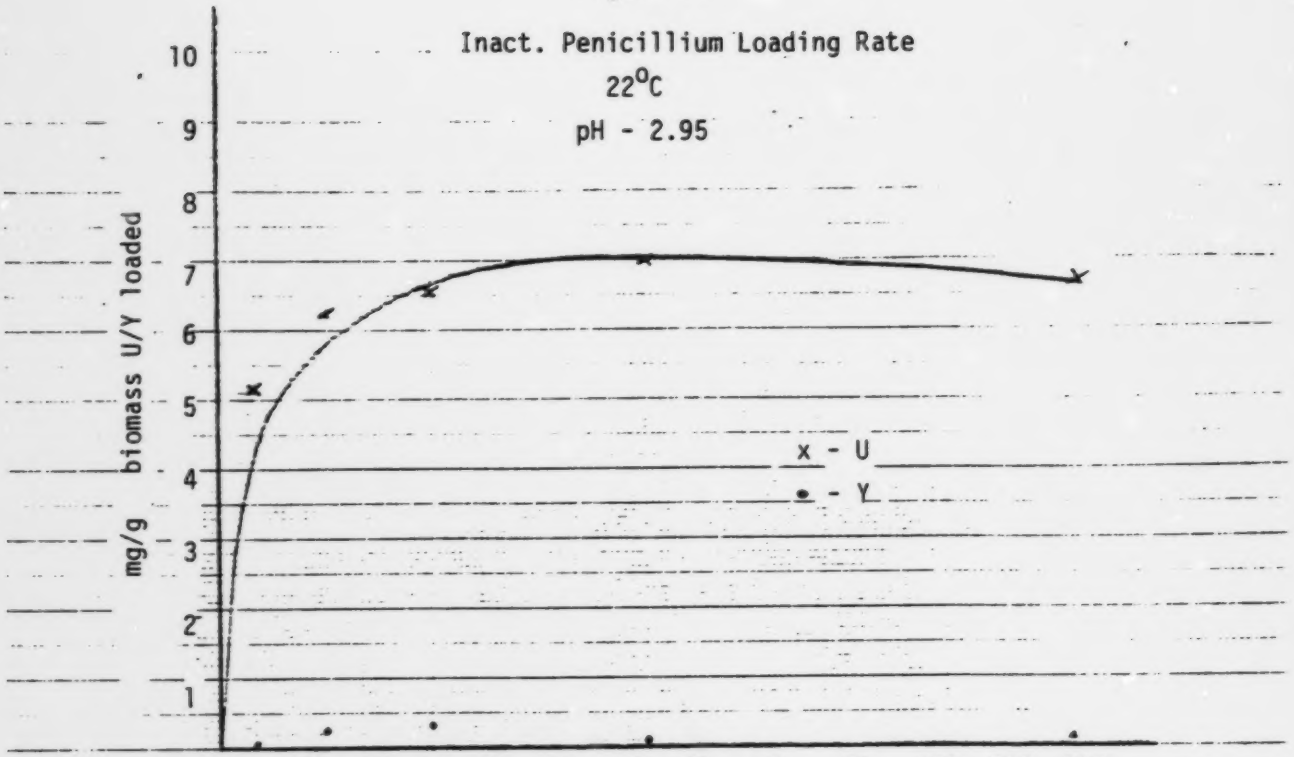


Figure 14

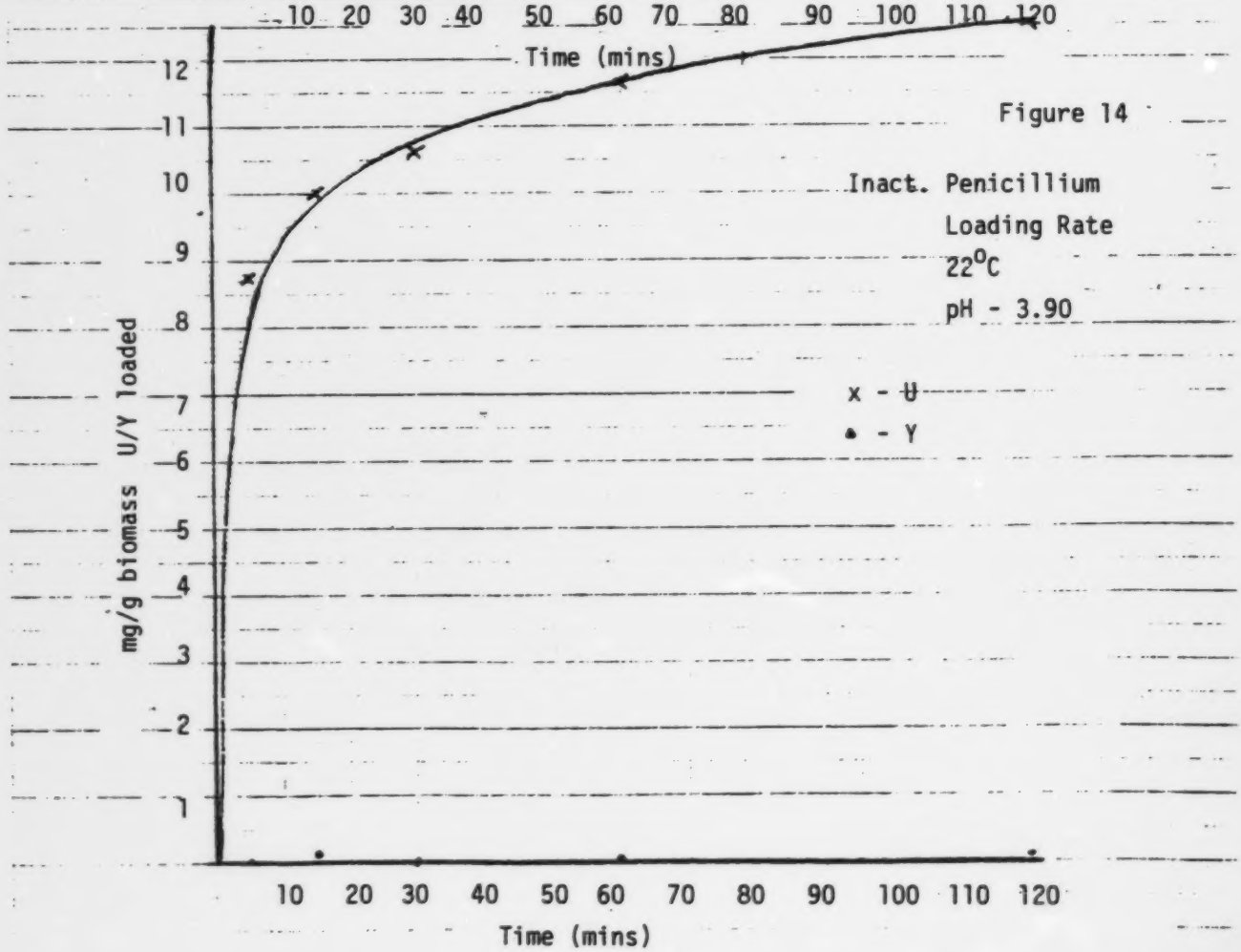


Figure 15

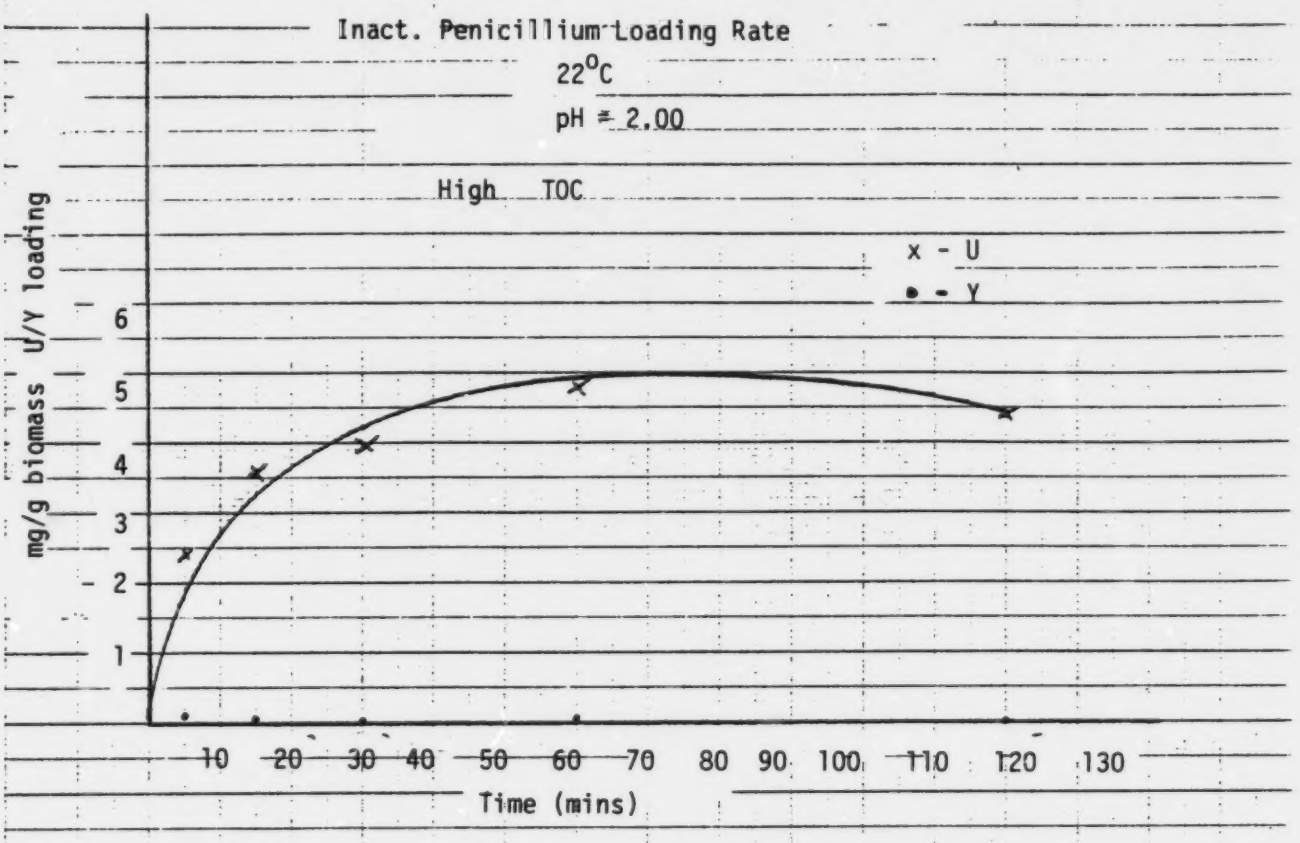

Inact. Penicillium Loading Rate
22°C
pH = 2.00
High TOC
x - U
• - Y
mg/g biomass U/Y loading
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100
110
120
130
Time (mins)

FIGURE 16

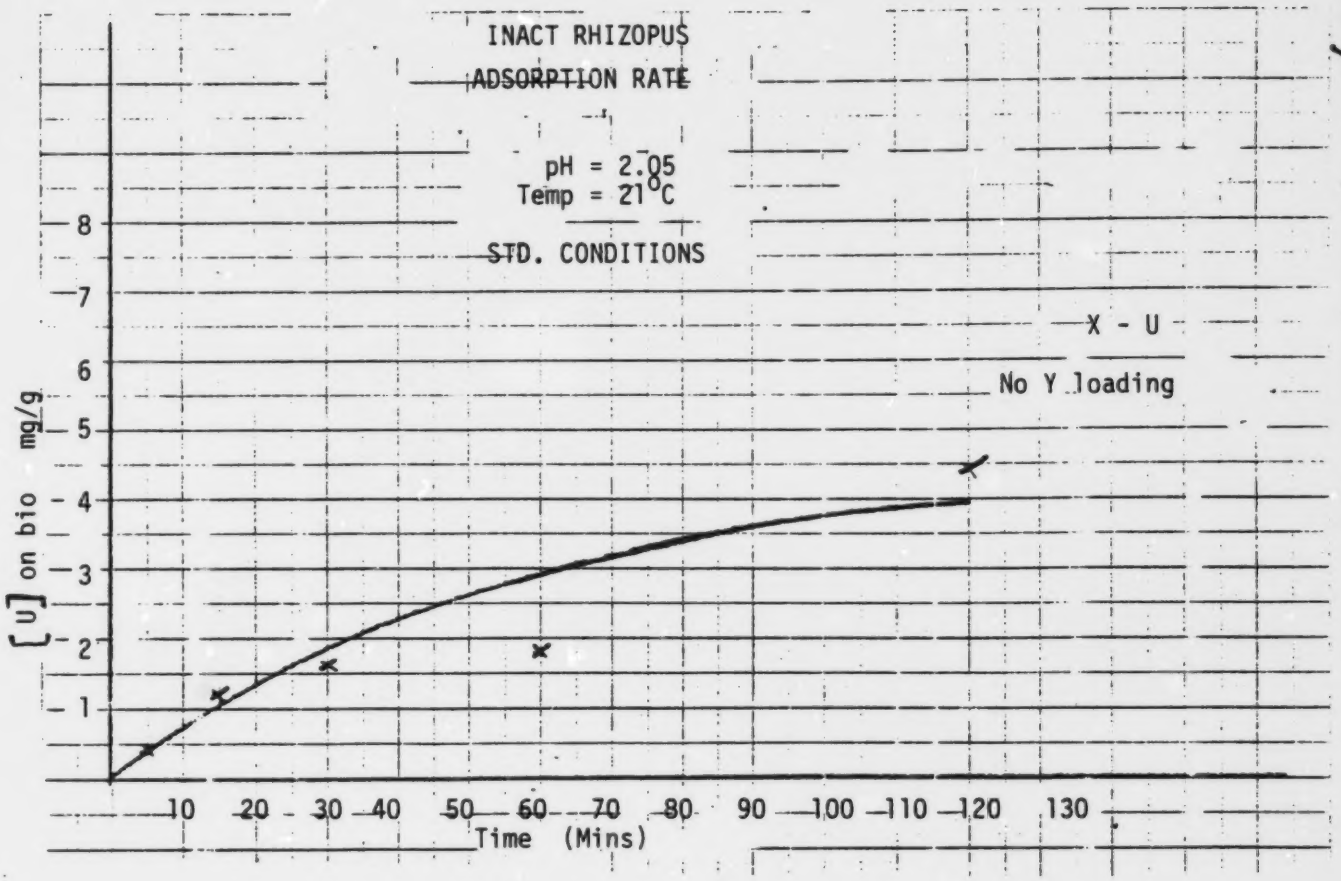

INACT RHIZOPUS
ADSORPTION RATE
pH = 2.05
Temp = 21°C
STD. CONDITIONS
X - U
No Y loading
[U] on bio mg/g
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
90
100
110
120
130
Time (Mins)

Figure 17

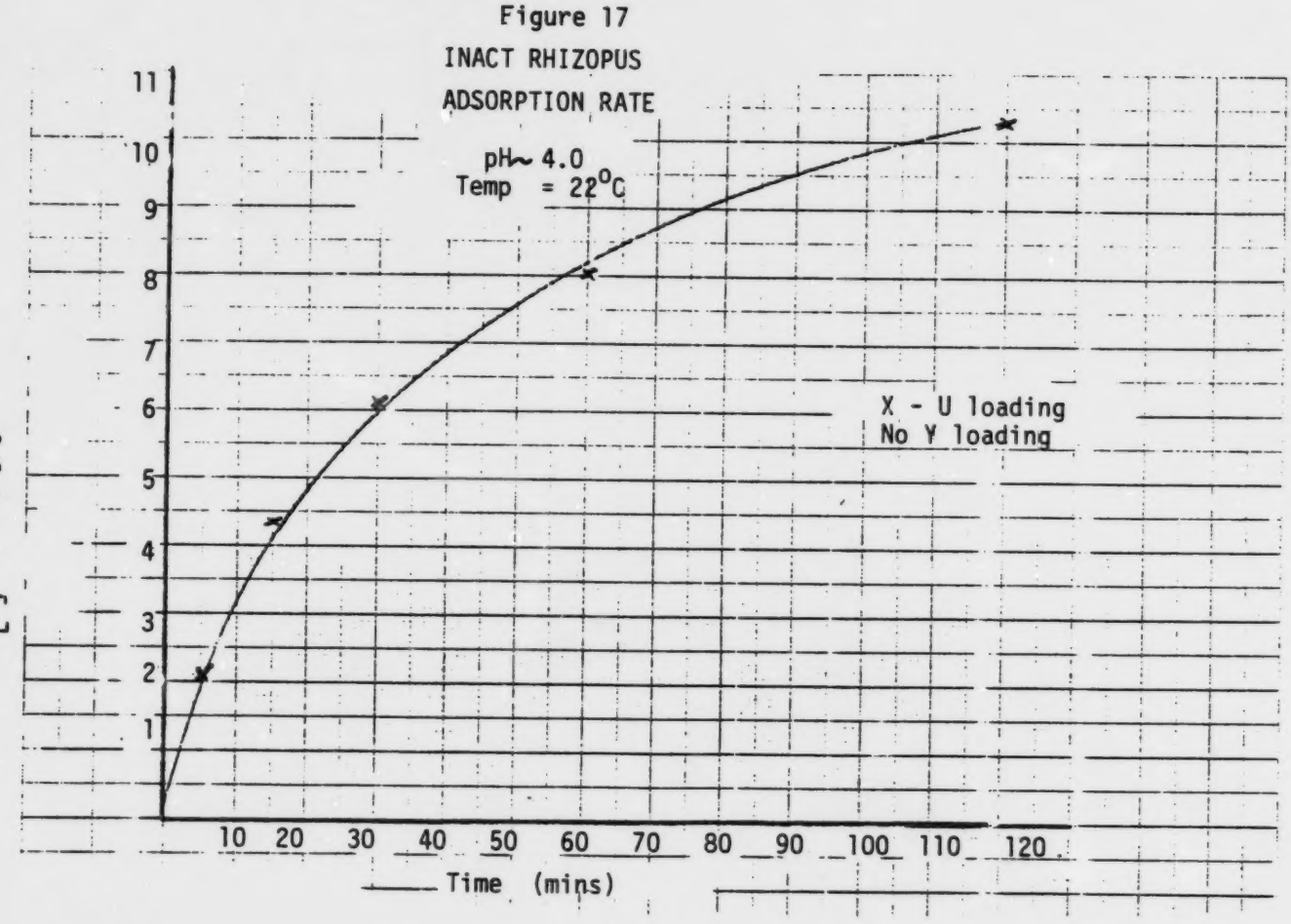

INACT RHIZOPUS
ADSORPTION RATE
pH~ 4.0
Temp = 22°C
X - U loading
No Y loading
[U] bio (mg/g)
11
10
9
8
7
6
5
4
3
2
1
10 20 30 40 50 60 70 80 90 100 110 120
Time (mins)

Figure 18

Inactivated Actinomycete
Equilibrium Adsorption

24°C

pH 2.95

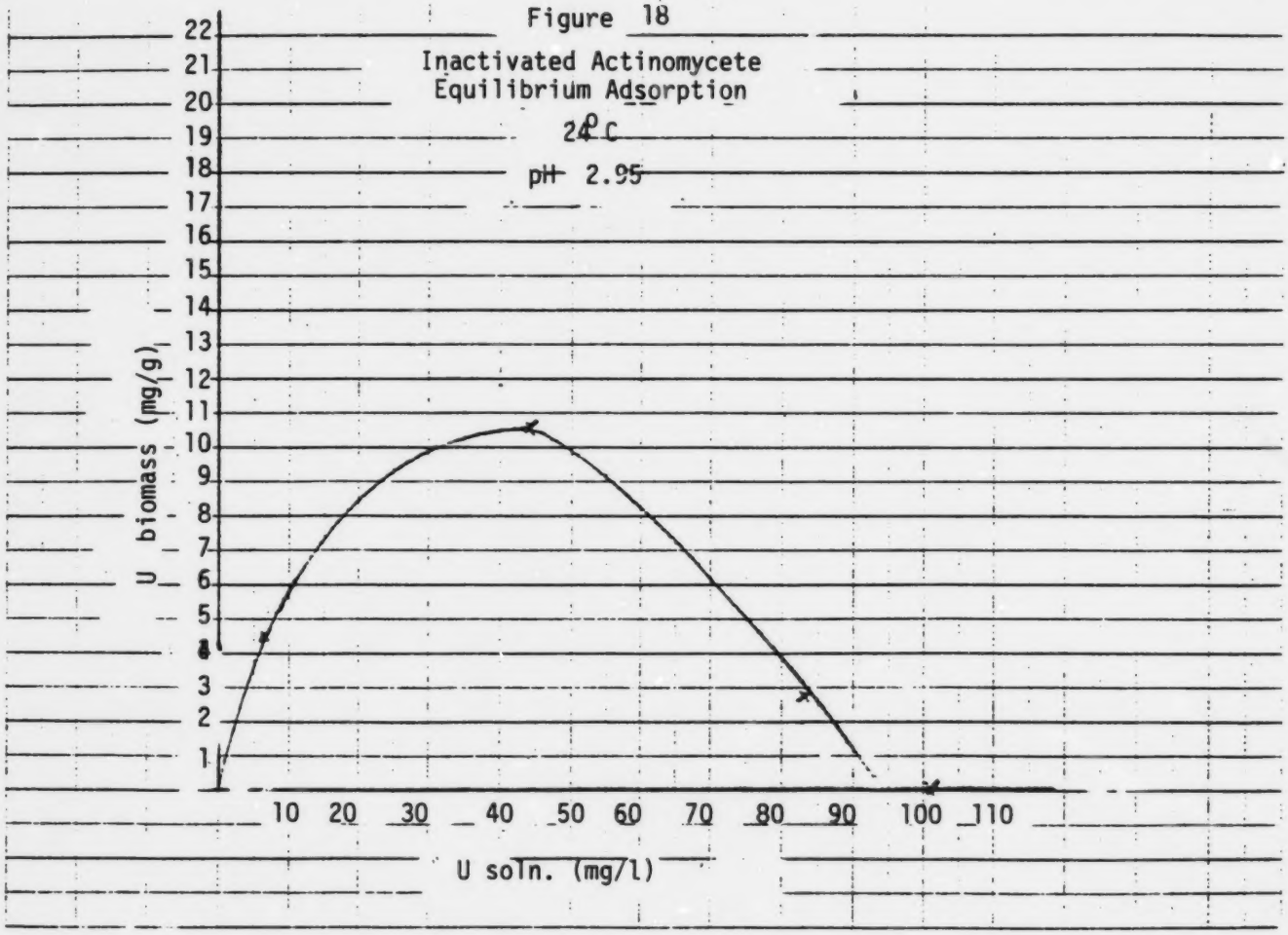


Figure 19

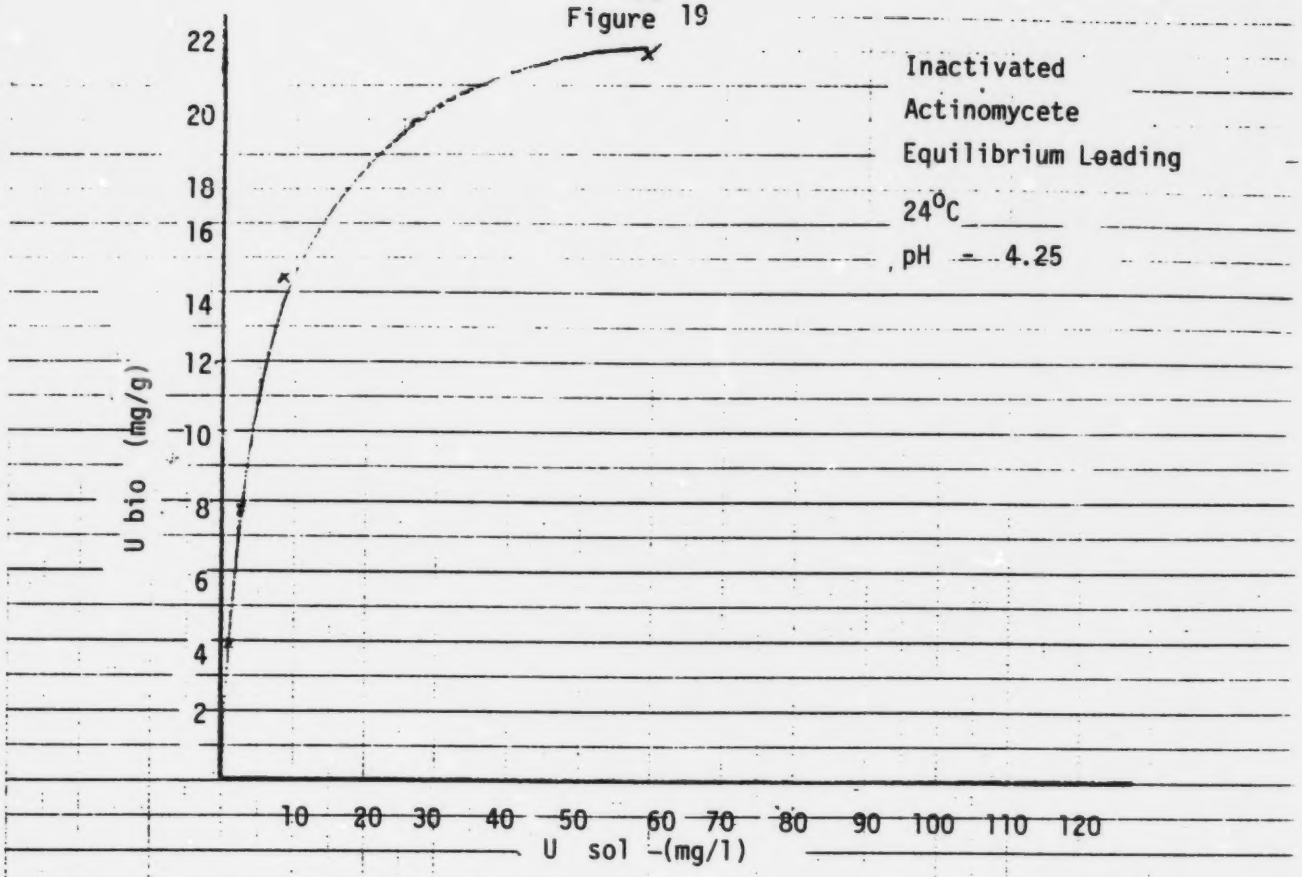


Figure 20

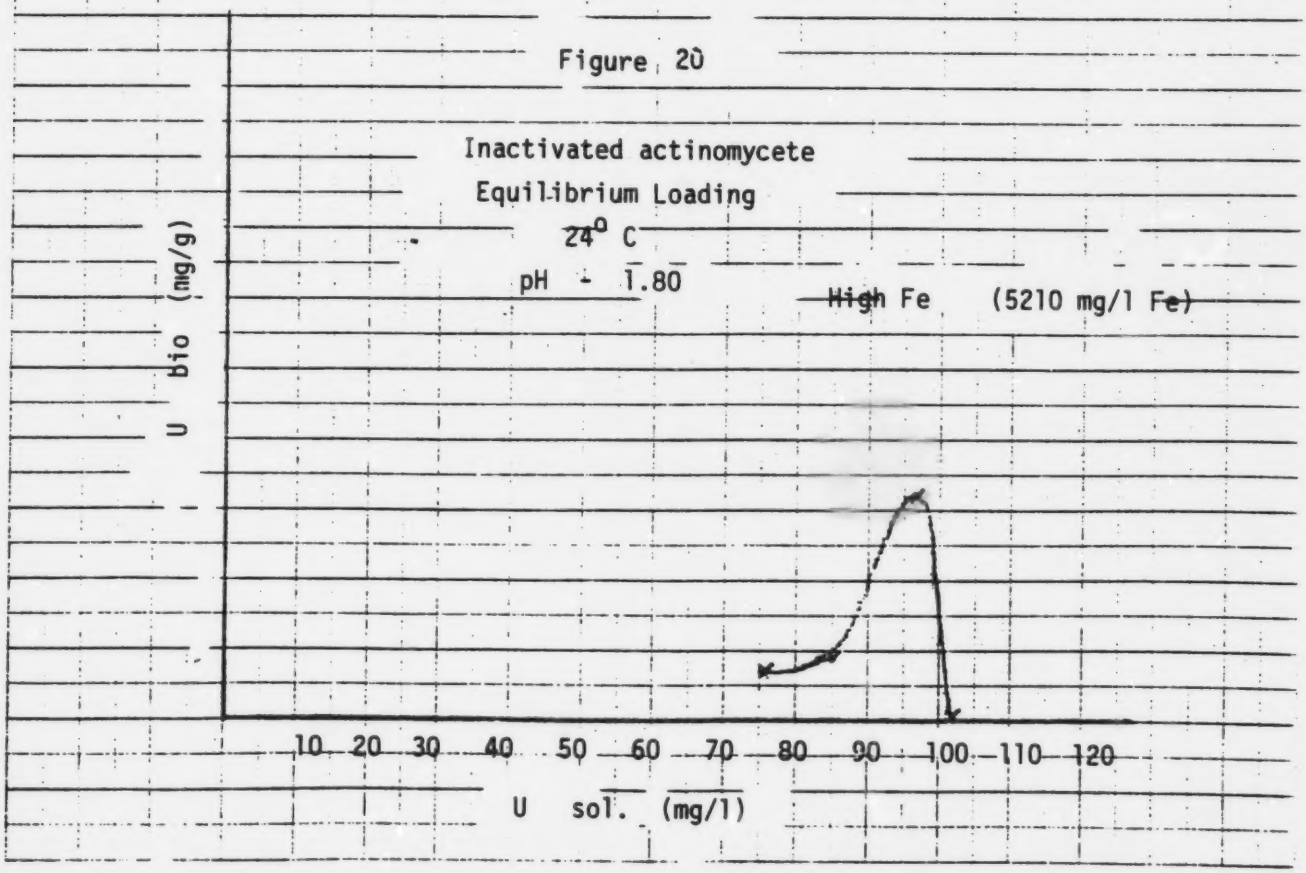

Inactivated actinomycete
Equilibrium Loading
24° C
pH - 1.80
High Fe (5210 mg/l Fe)
U bio (mg/g)
10 20 30 40 50 60 70 80 90 100 110 120
U sol. (mg/l)

Figure 21

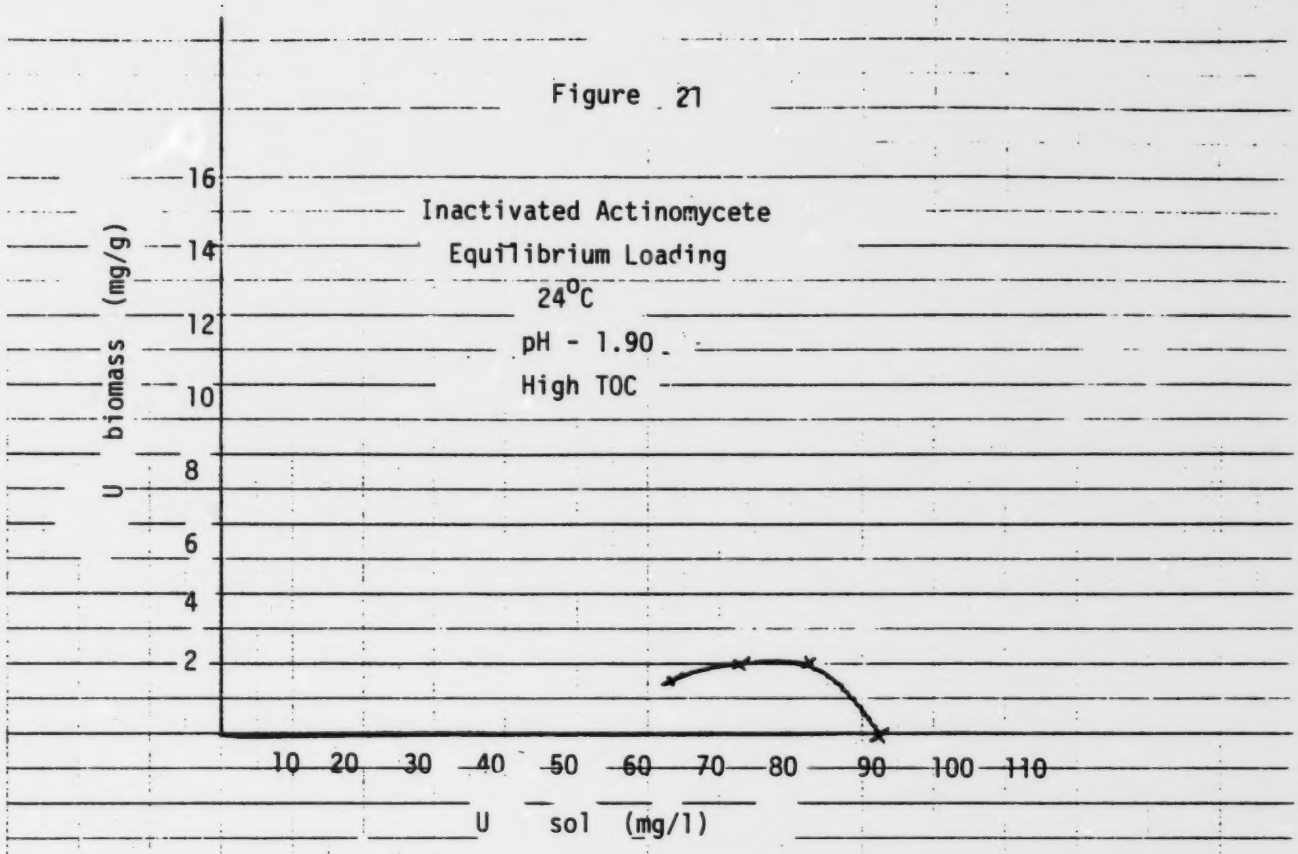


Figure 22

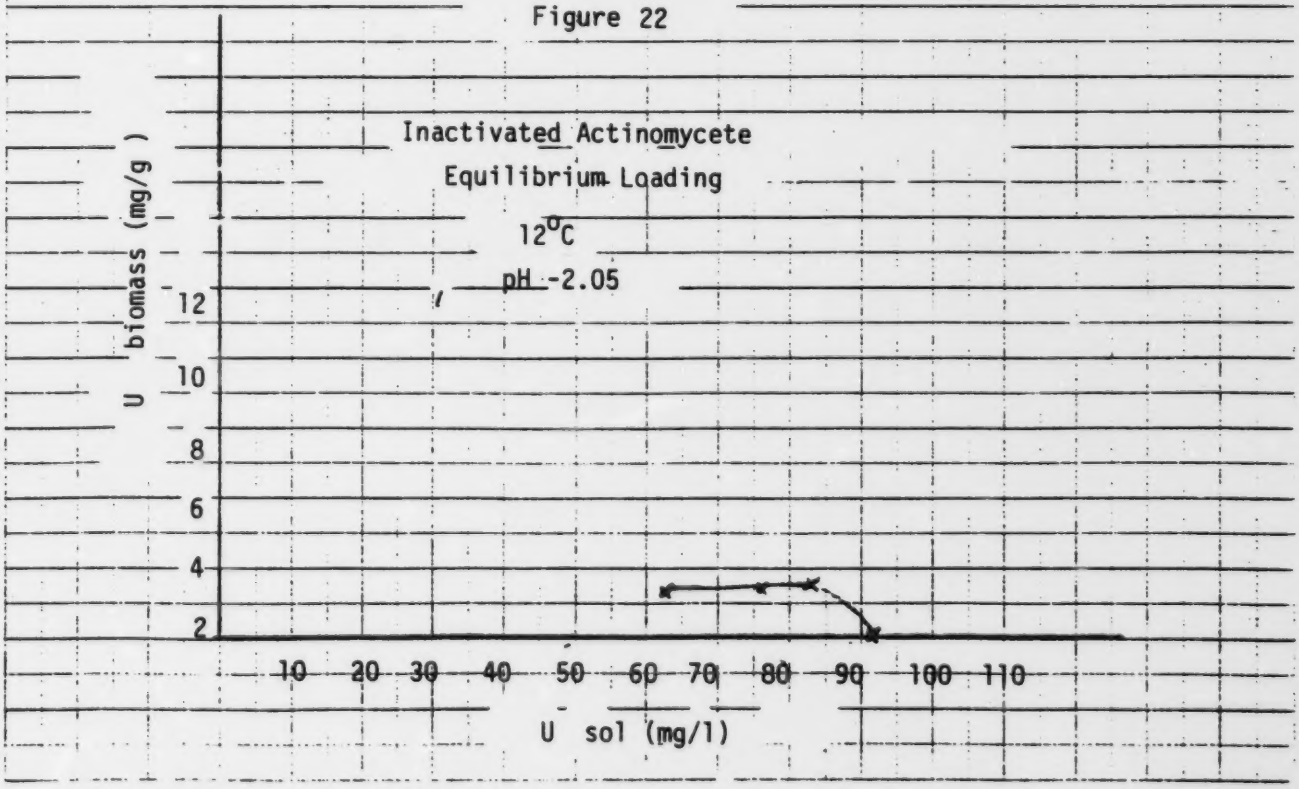


Figure 23

Inact. Penicillium Equilibrium Loading

21°C

pH - 2.00

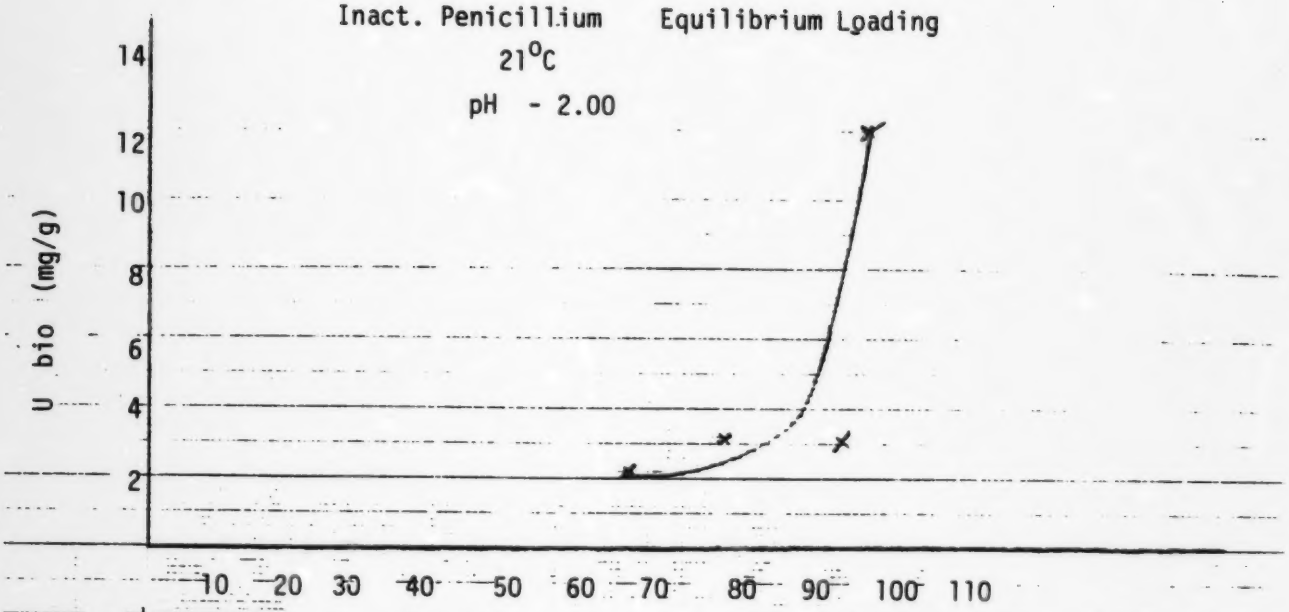


Figure 24

Inact. Penicillium Equilibrium Adsorption

21°C

pH 2.95

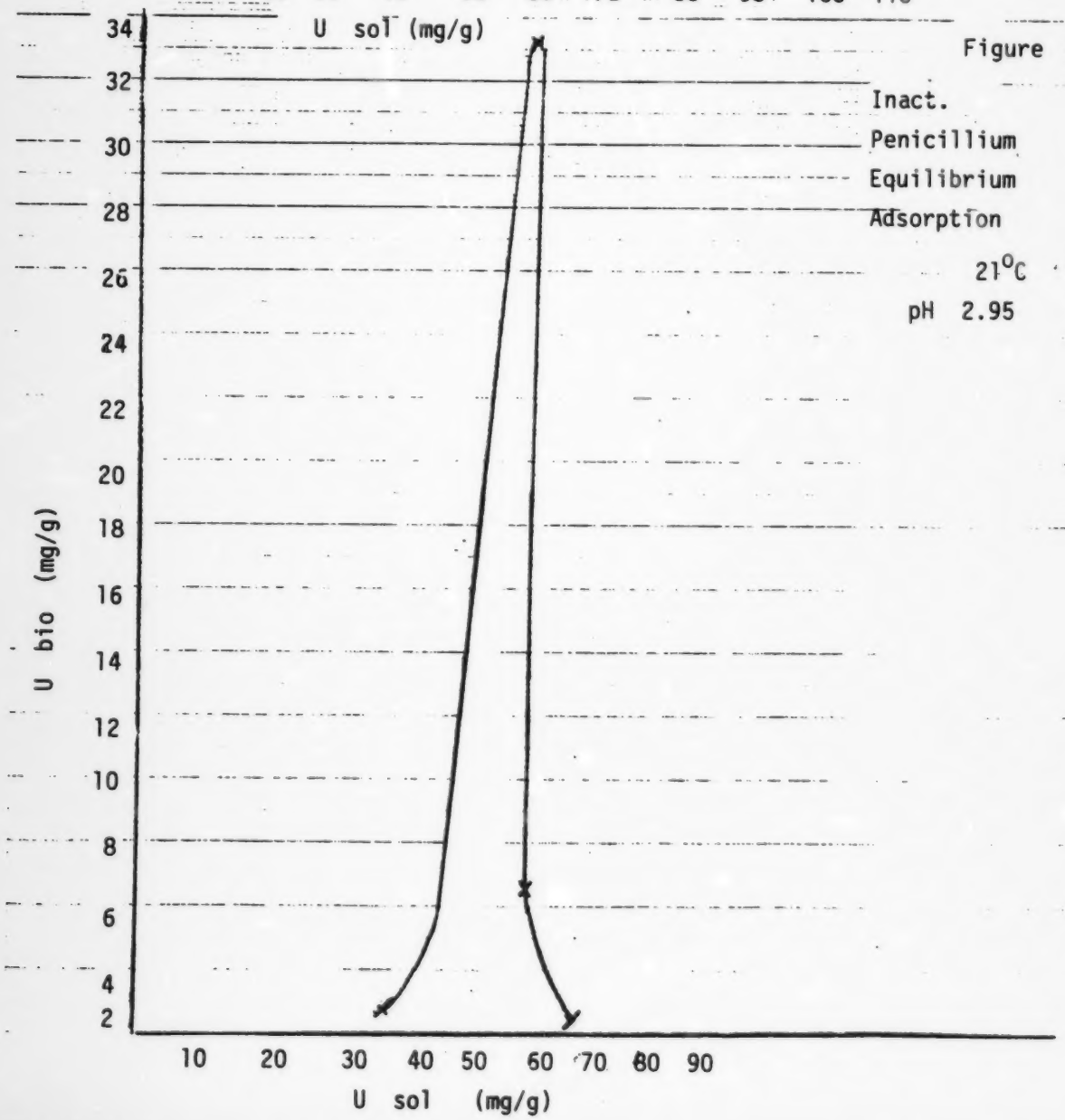


Figure 25

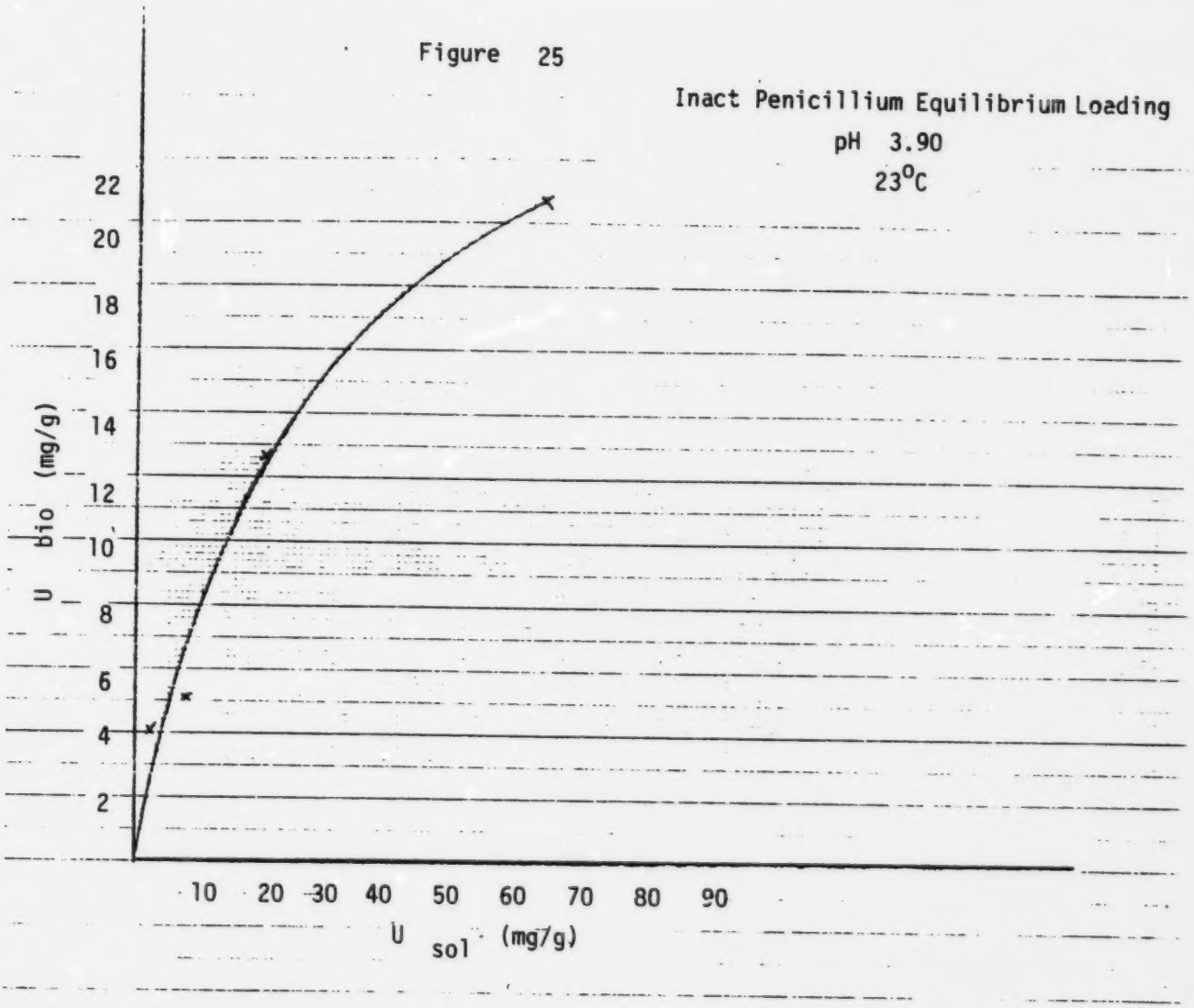

Inact Penicillium Equilibrium Loading
pH 3.90
23°C
U bio (mg/g)
22
20
18
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90
U sol (mg/g)

Figure 26

Inact. Penicillium Equilibrium Loading

2°C

pH = 2.00

High TOC

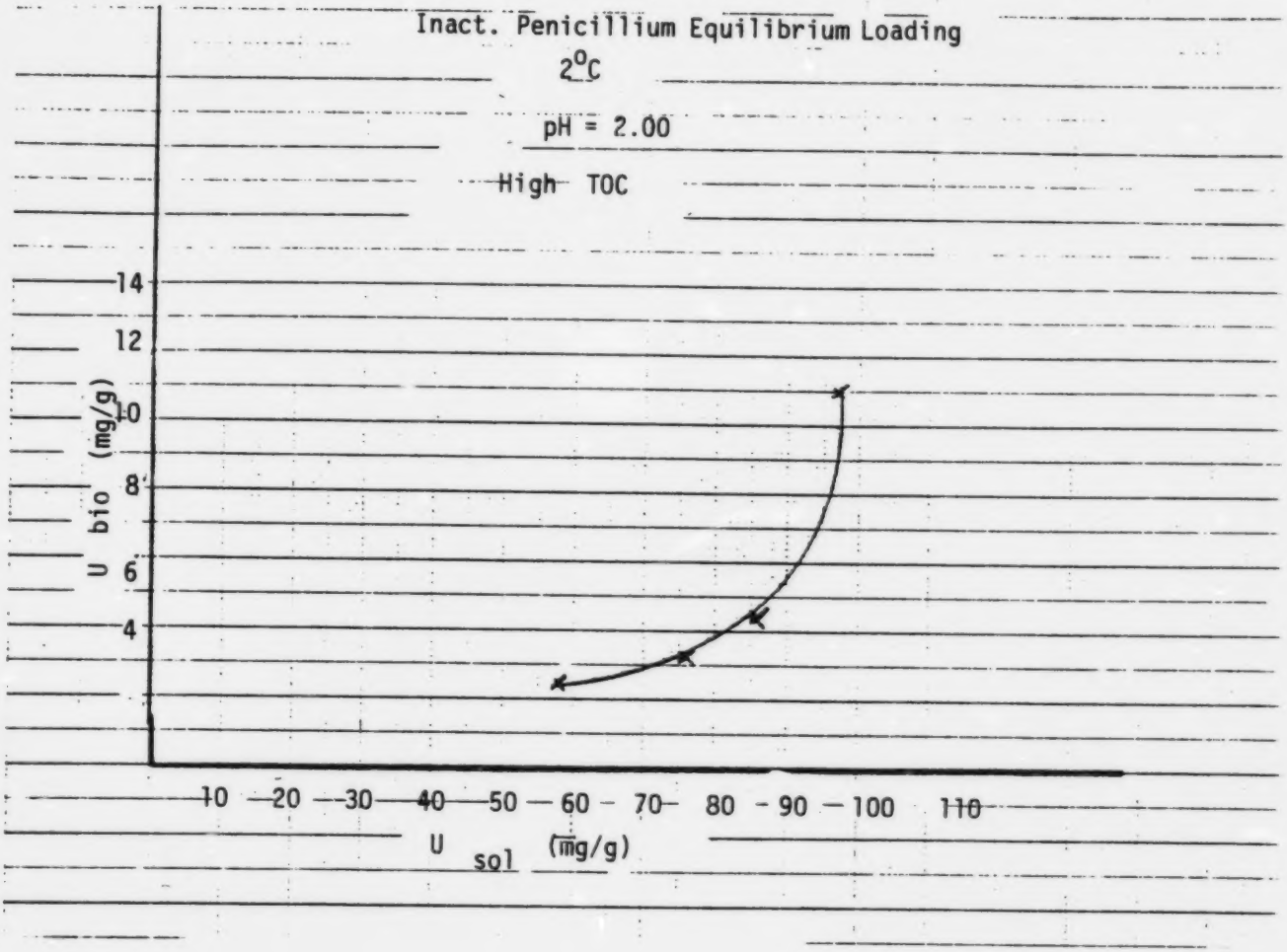


FIGURE 27
INACT RHIZOPUS
EQUILIBRIUM LOADING

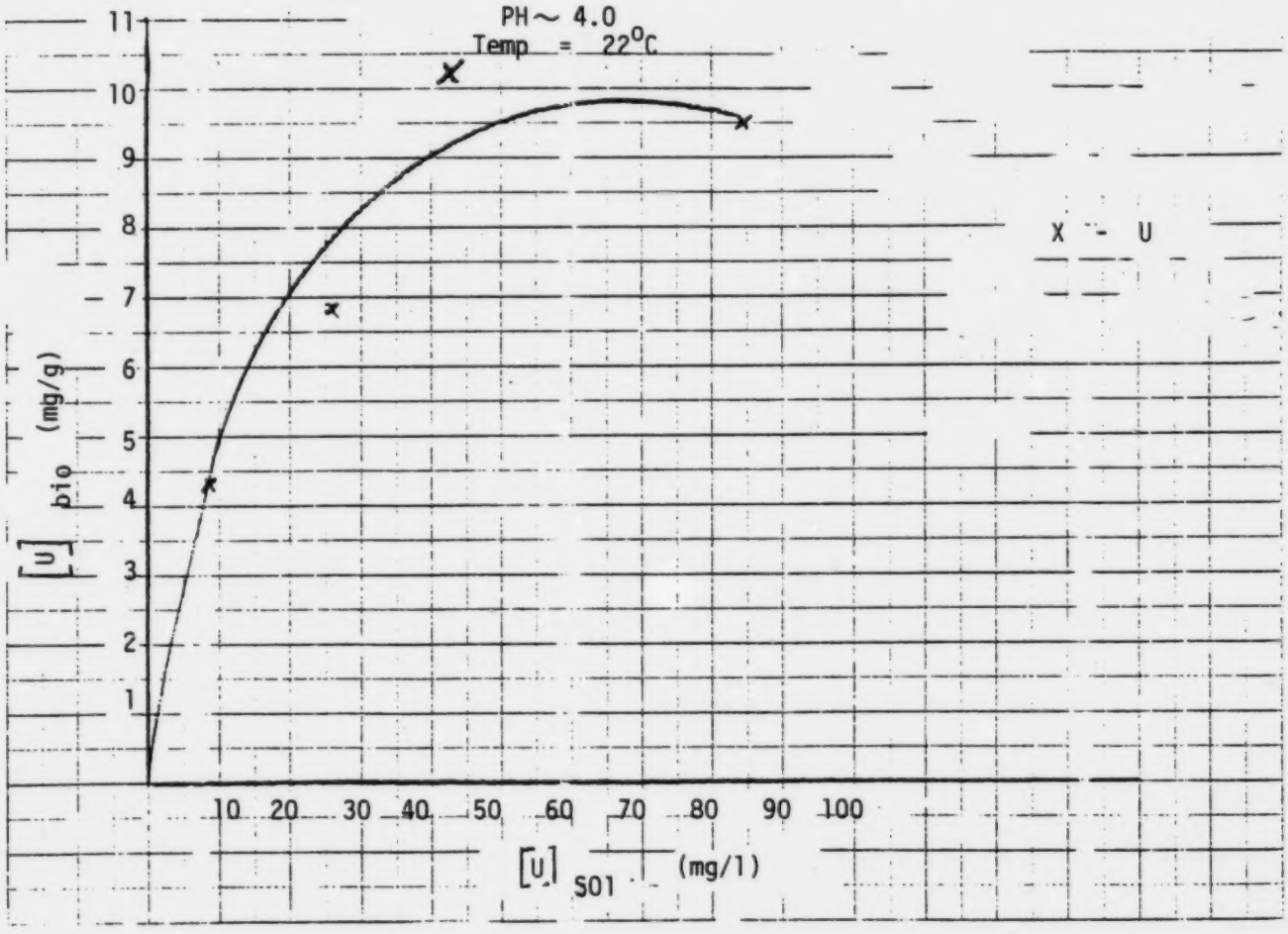


Figure 28

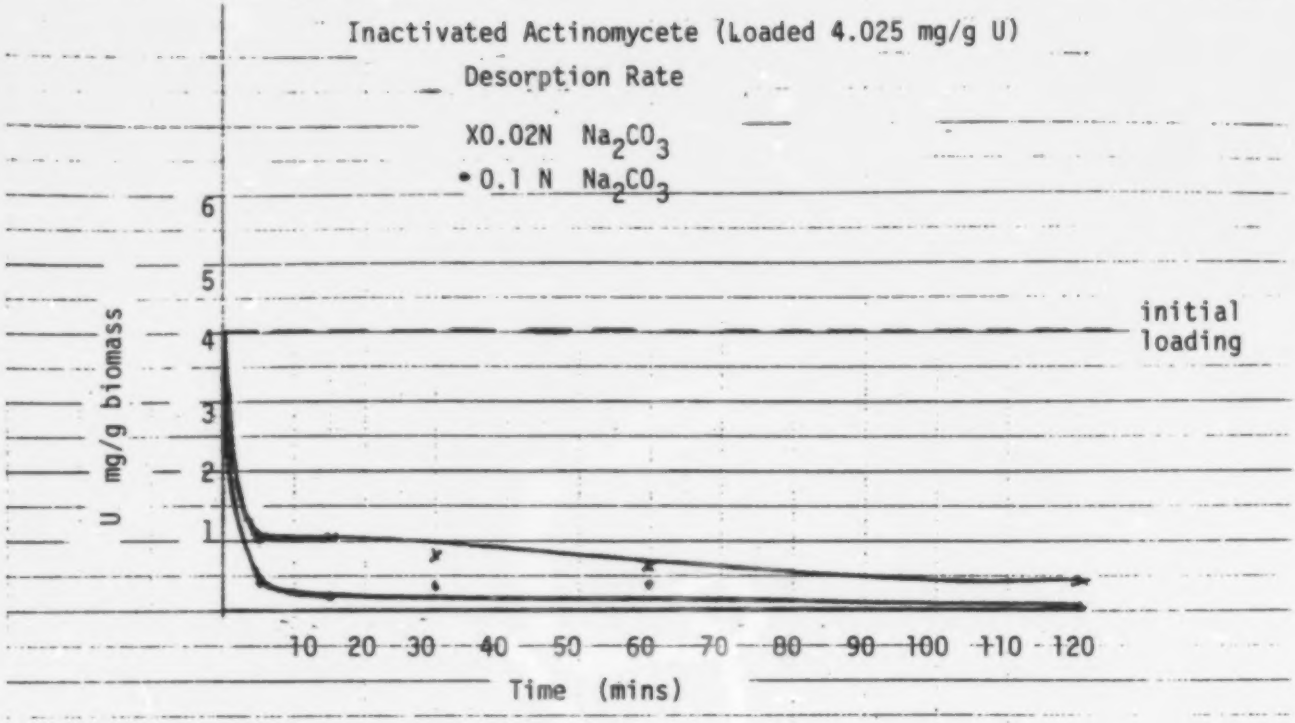


Figure 29

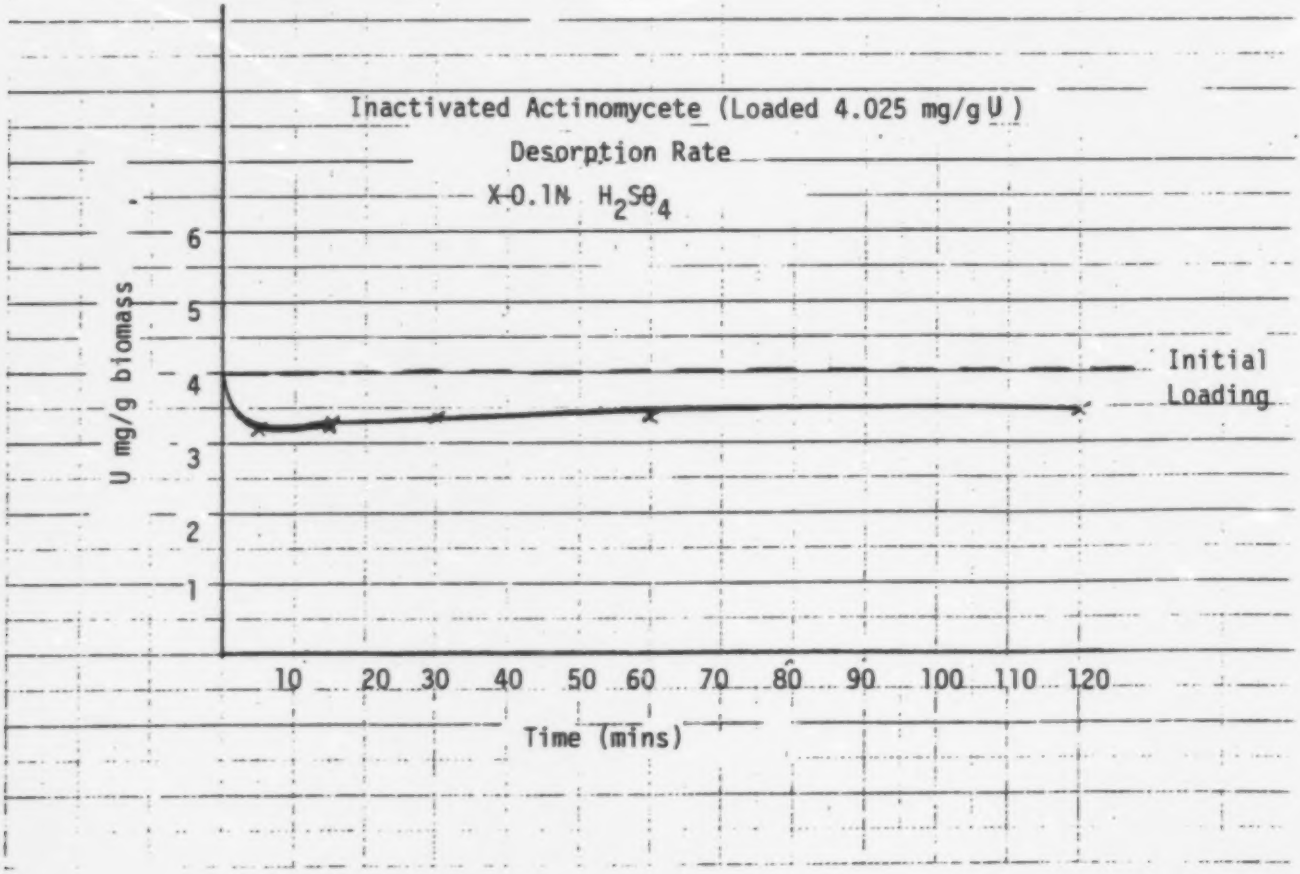


Figure 30

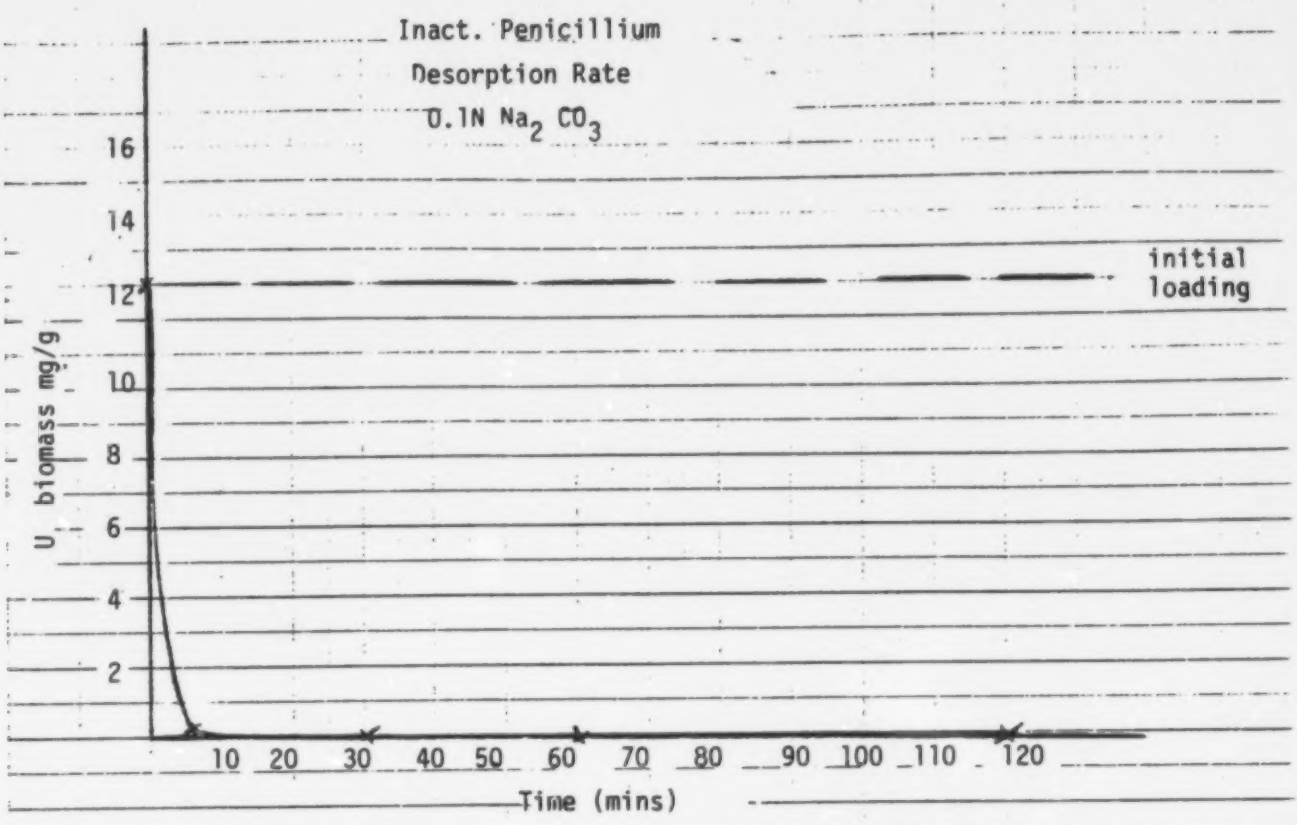


Figure 31

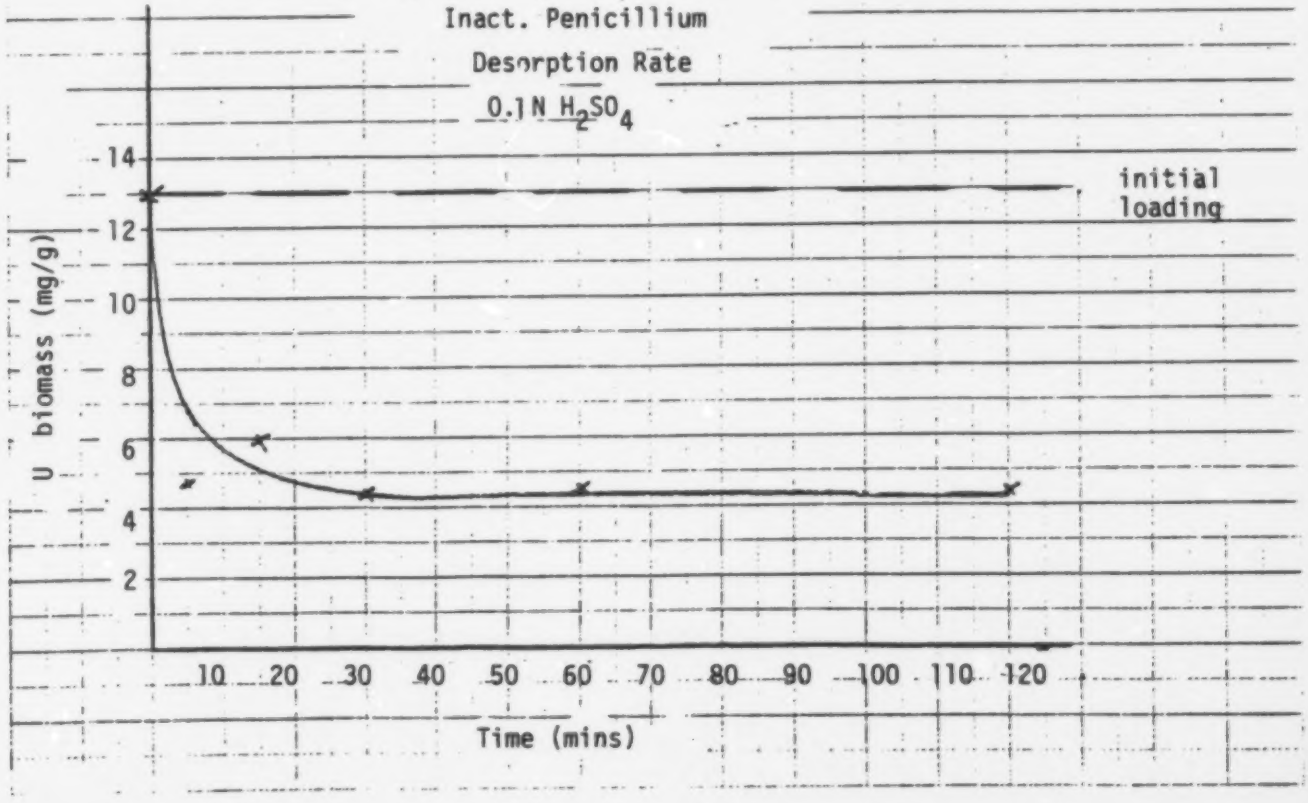


Figure 32

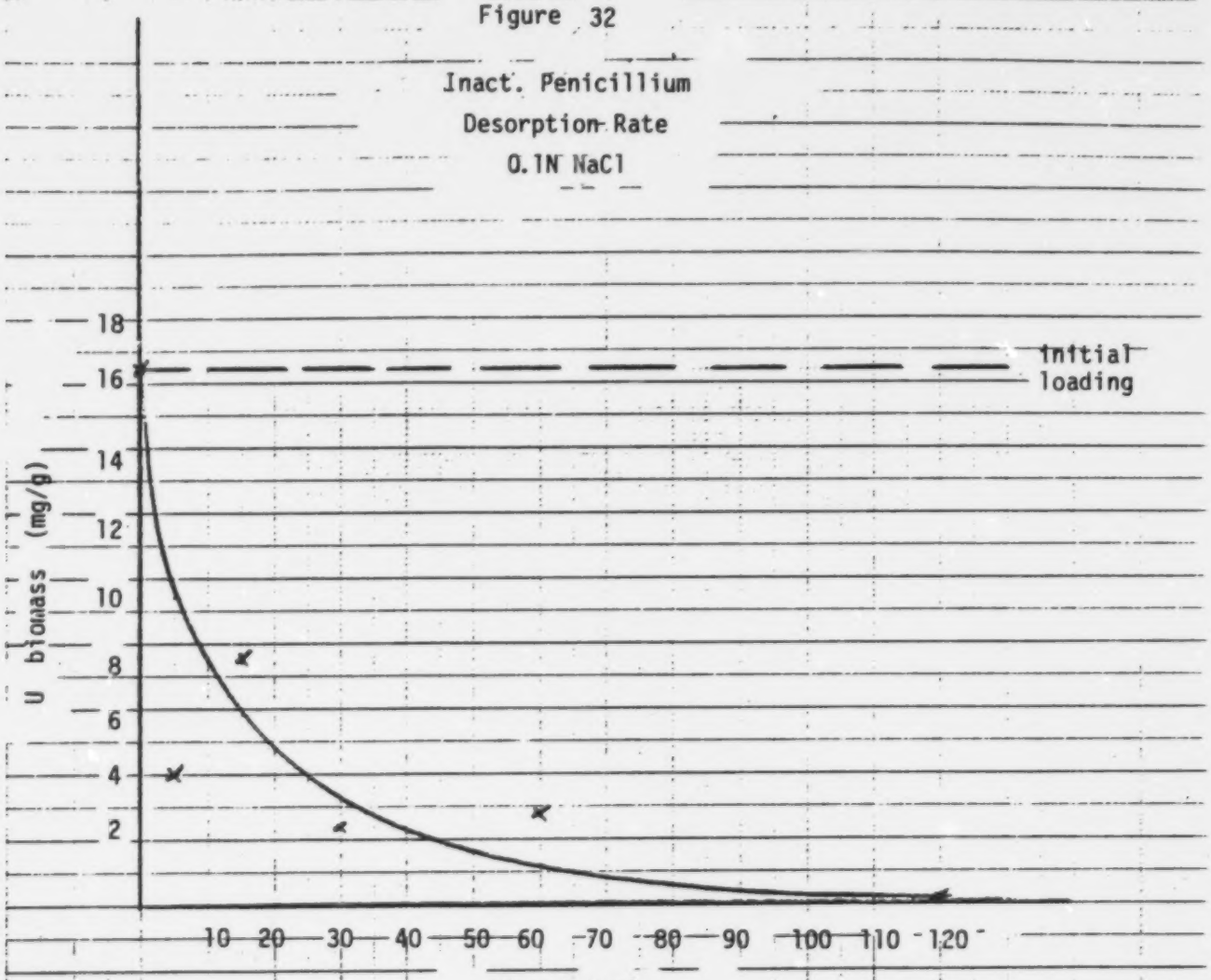
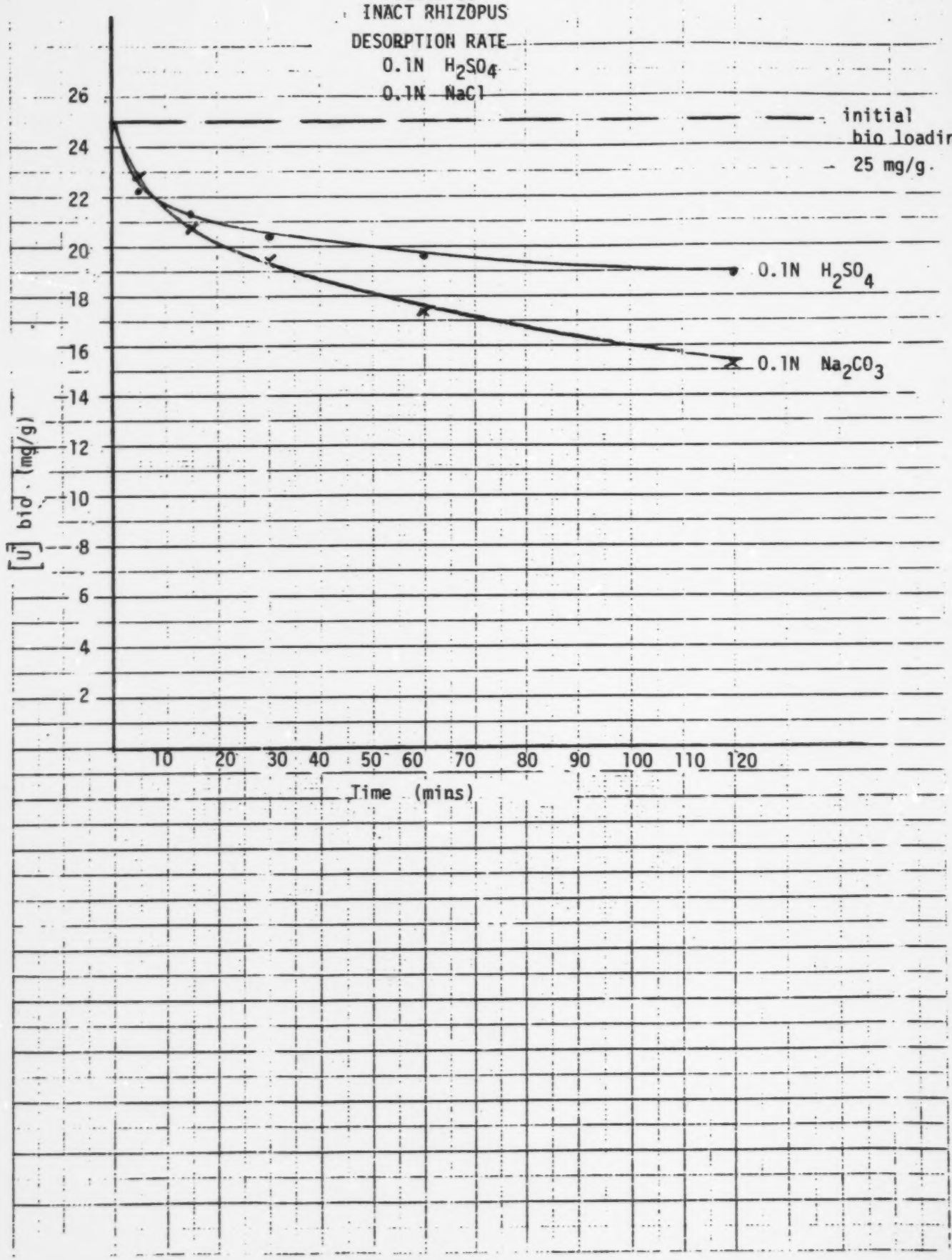

Inact. Penicillium
Desorption Rate
0.1N NaCl
initial loading
U biomass (mg/g)
18
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90 100 110 120
Time (mins)

FIGURE 33
INACT RHIZOPUS
DESORPTION RATE
0.1N H_2SO_4
0.1N NaCl



46 1510

FIGURE 34

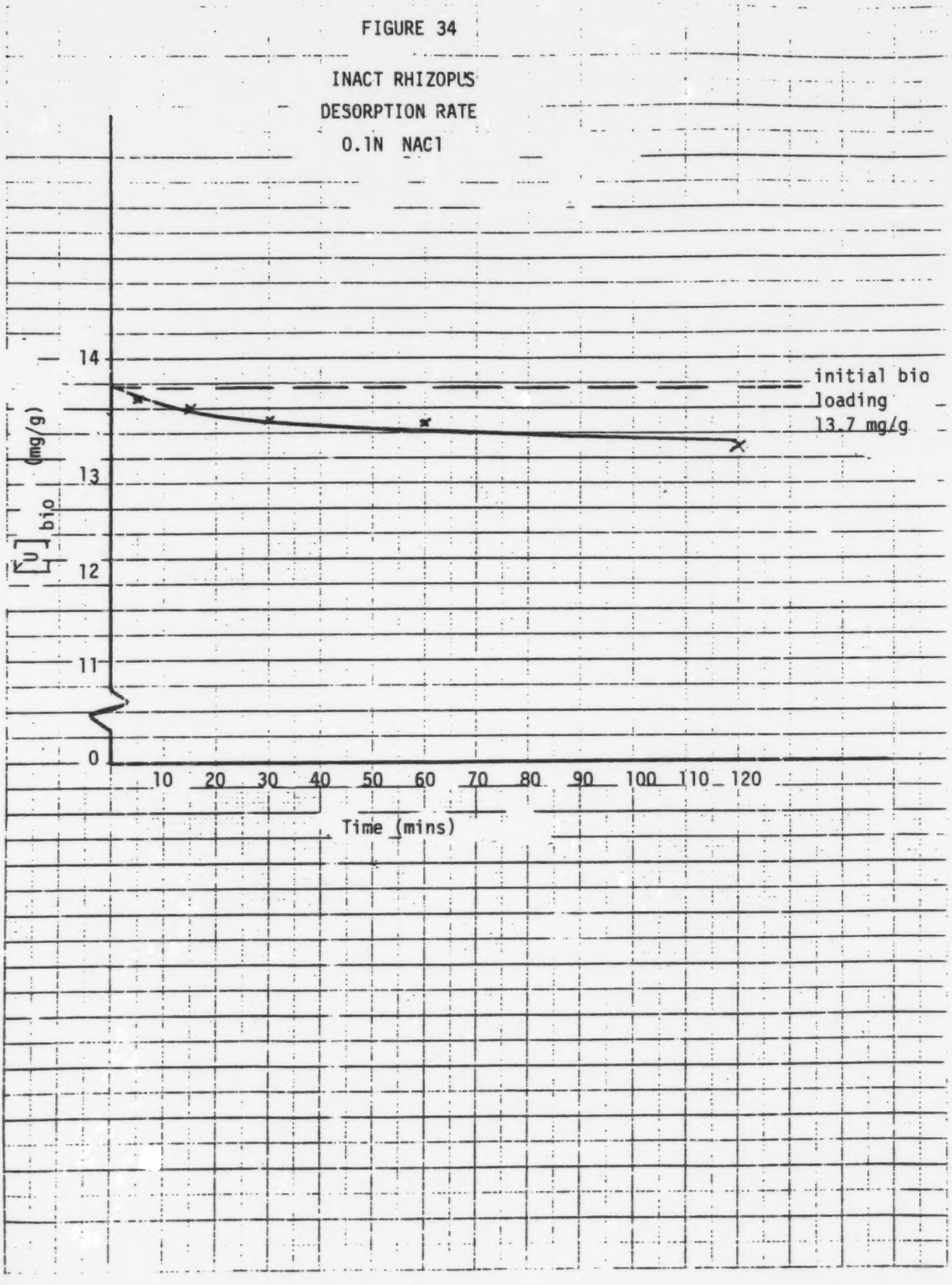

INACT RHIZOPUS
DESORPTION RATE
0.1N NACl
14
13
12
11
0
[U]bio (mg/g)
initial bio loading 13.7 mg/g
10 20 30 40 50 60 70 80 90 100 110 120
Time (mins)

Figure 35

Inactivated Actinomycete (Loaded 4.025 mg/g)

Desorption - Equilibrium

22° C

x 0.02N Na_2CO_3

0.1N Na_2CO_3

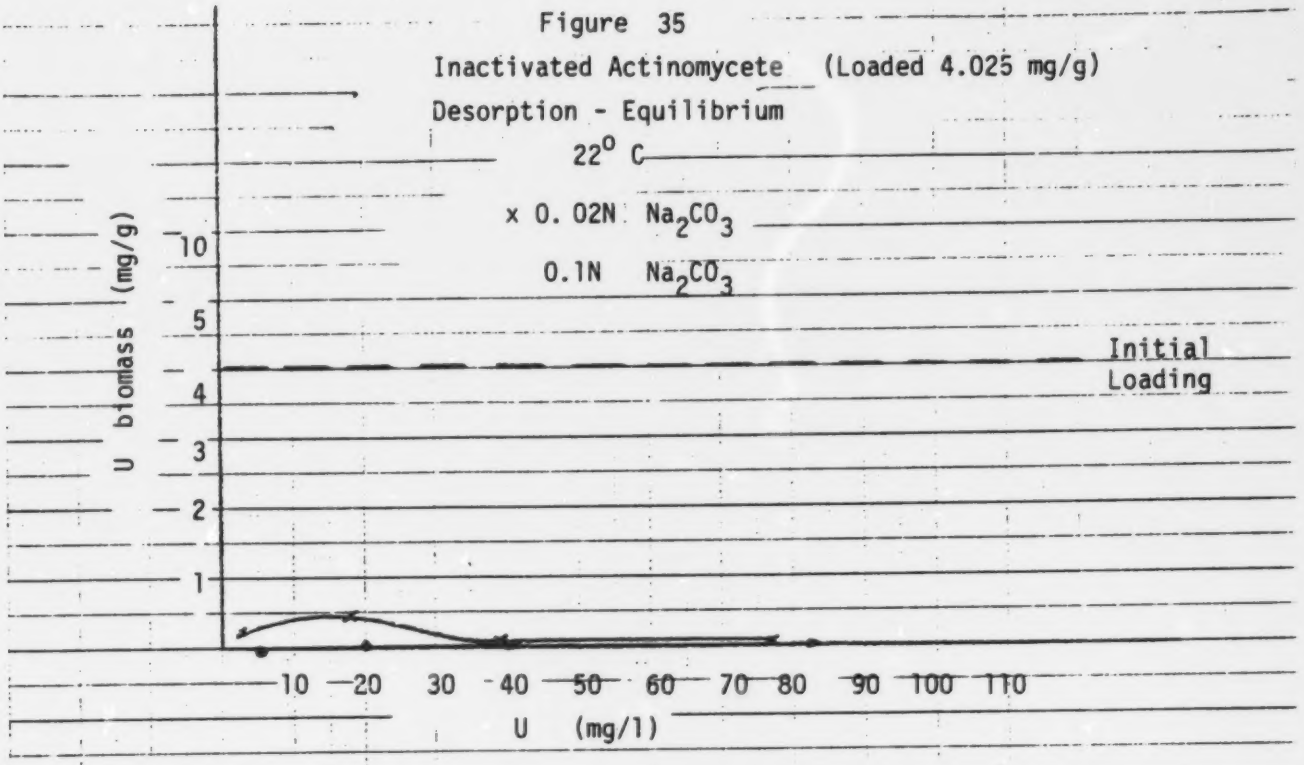


Figure 36

Inactivated Actinomycete (Loaded 4.02 mg/g U)

Desorption - Equilibrium

22°C

X 0.1N H_2SO_4

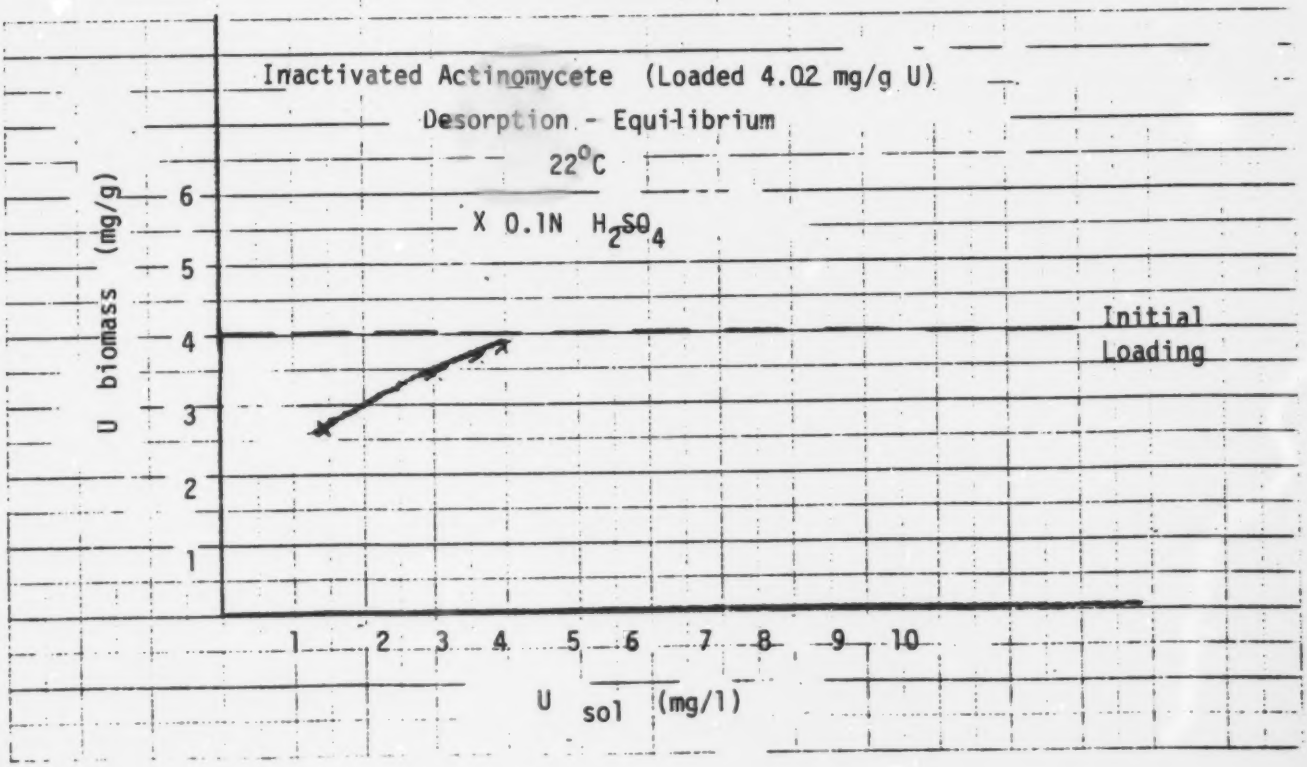


FIGURE 37
INACT. PENICILLIUM (Loaded to 16 mg/g)
EQUILIBRIUM DESORPTION
0.1N Na_2CO_3

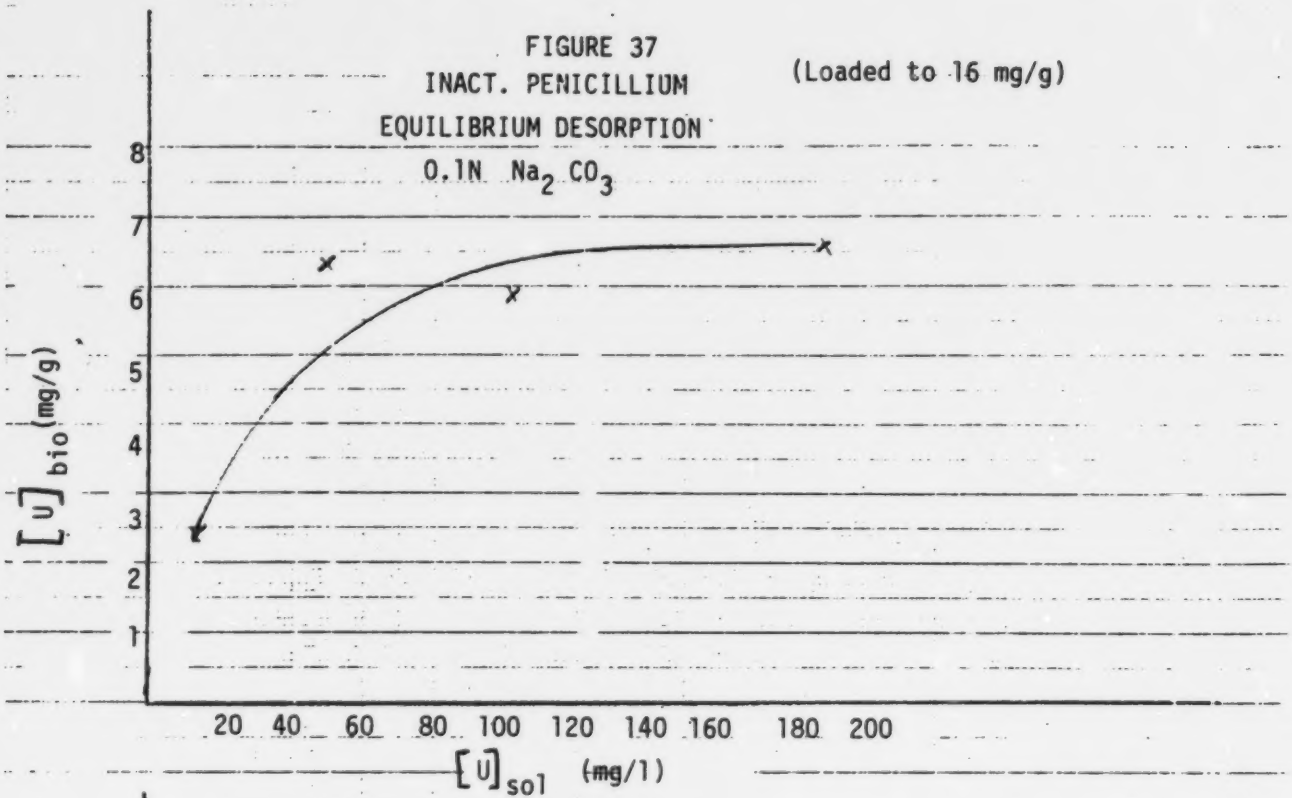


FIGURE 38
Inact Penicillium (Loaded to 12 mg/g)
Equilibrium Desorption
0.1N H_2SO_4

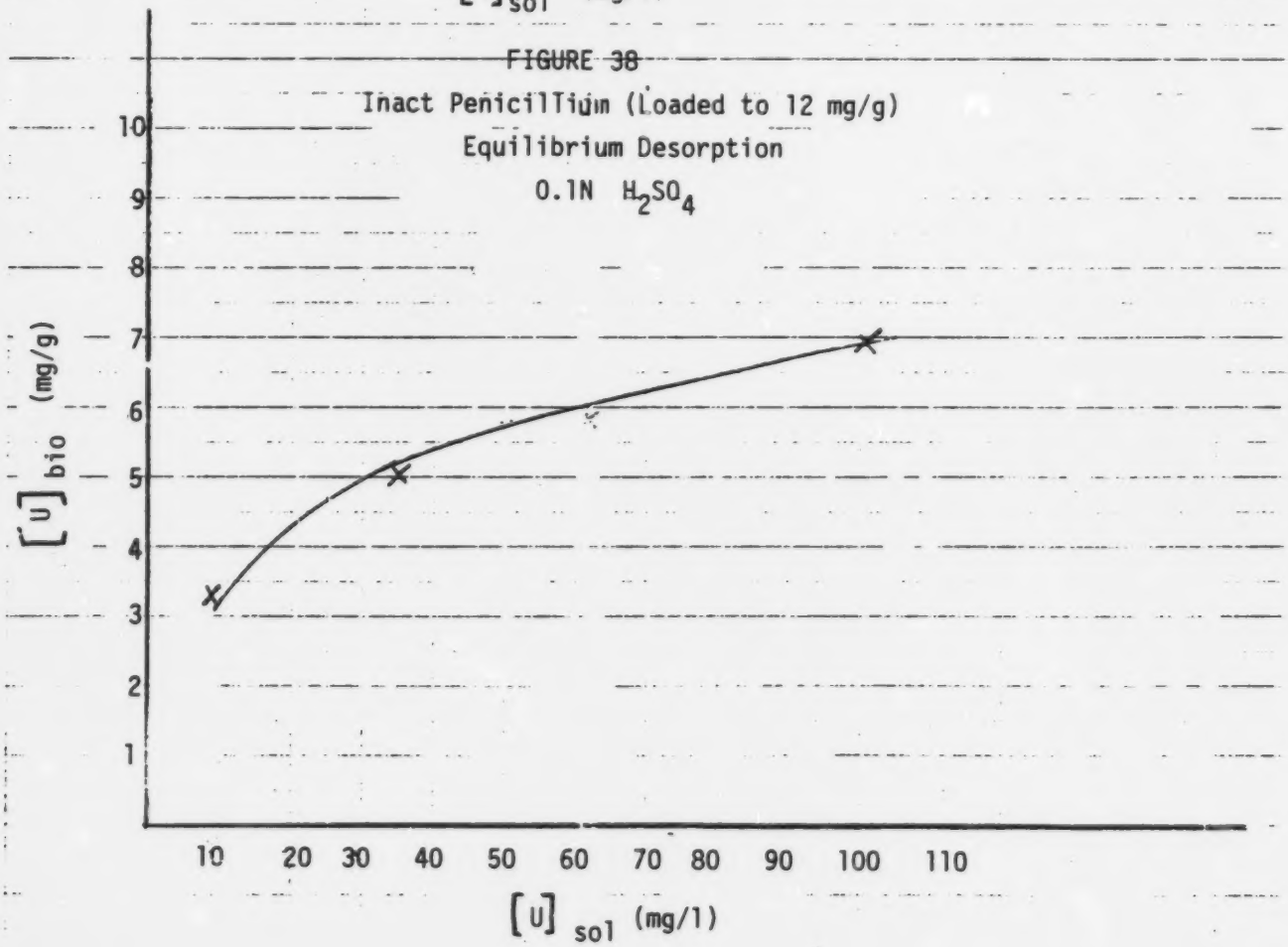
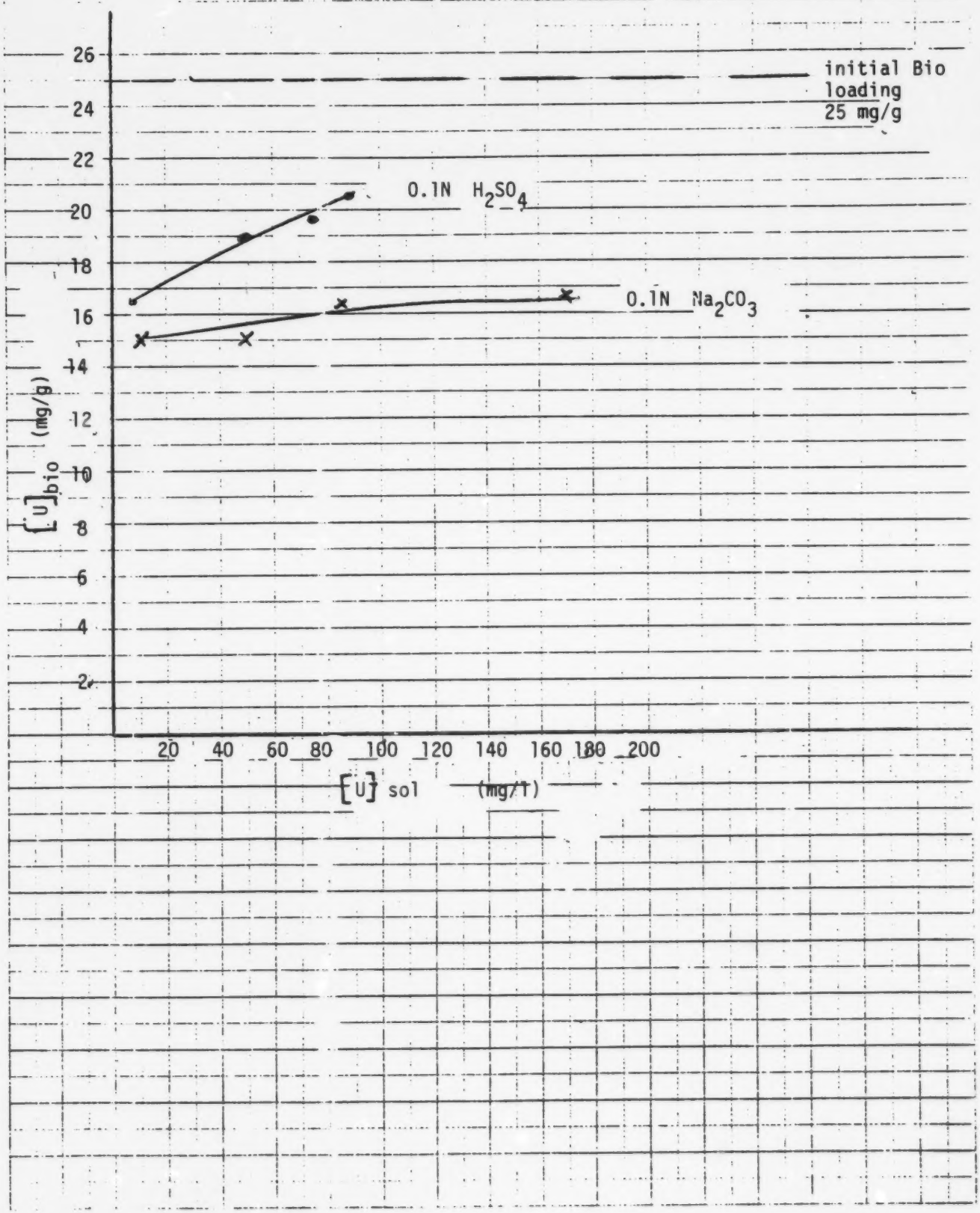


FIGURE 39

INACT_RHIZOPUS

EQUILIBRIUM DESORPTION



461510

Table 3

Actinomycete Size Distribution Before Continuous Testing

Mesh Size	% Retained	Cum. % Passing
14	7.7	92.3
24	16.6	75.7
48	35.7	40.0
65	9.5	30.5
-65	30.5	-
	100.0	

Fig. 4

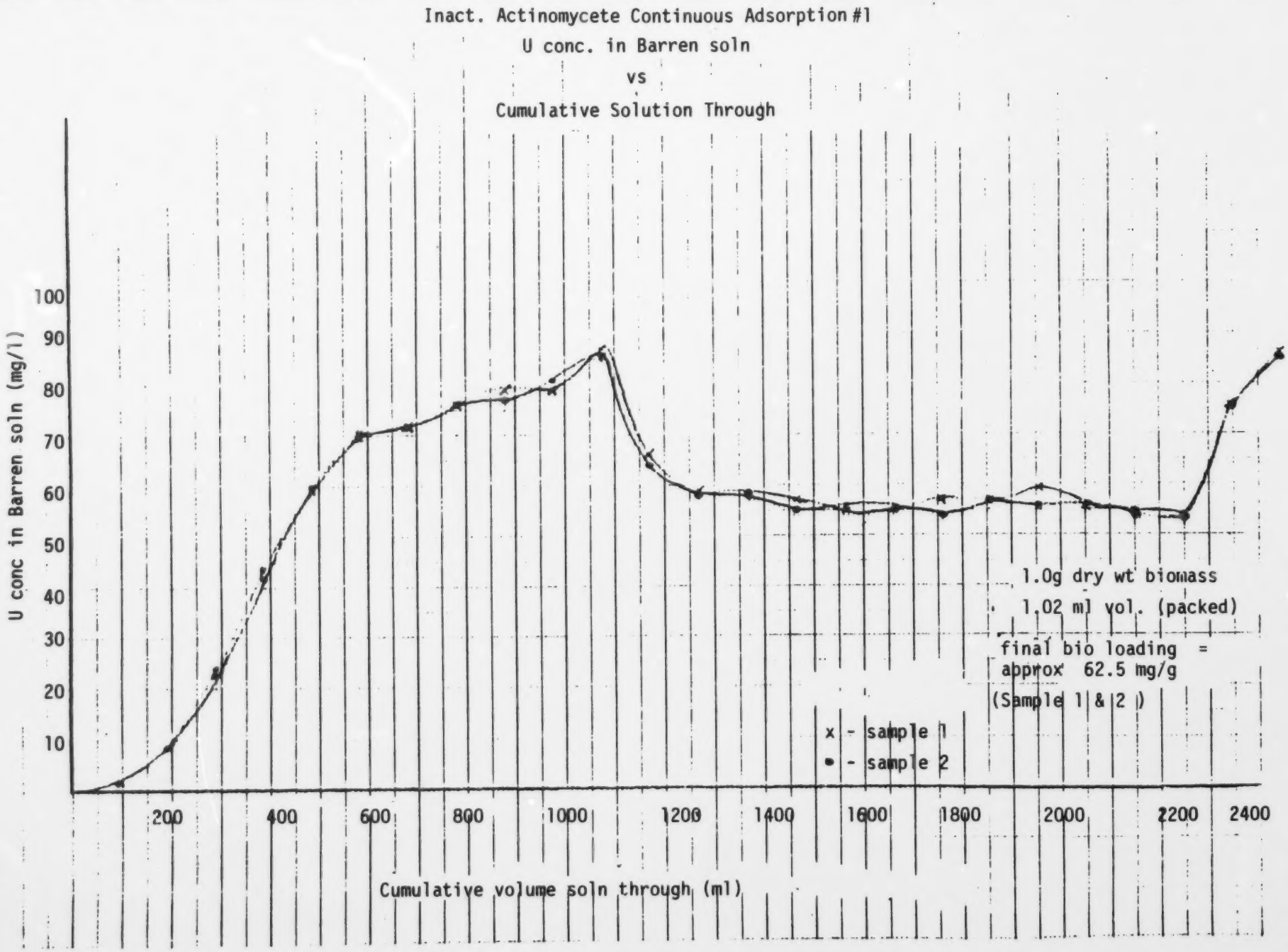

Inact. Actinomycete Continuous Adsorption #1
U conc. in Barren soln
vs
Cumulative Solution Through
U conc in Barren soln (mg/l)
100
90
80
70
60
50
40
30
20
10
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Cumulative volume soln through (ml)
1.0g dry wt biomass
1.02 ml vol. (packed)
final bio loading =
approx 62.5 mg/g
(Sample 1 & 2)
x - sample 1
• - sample 2

FIGURE 41

INACT. ACTINOMYCETE CONTINUOUS DESORPTION #1

U CONC. IN ELUATE

vs

VOL. SOLN THROUGH

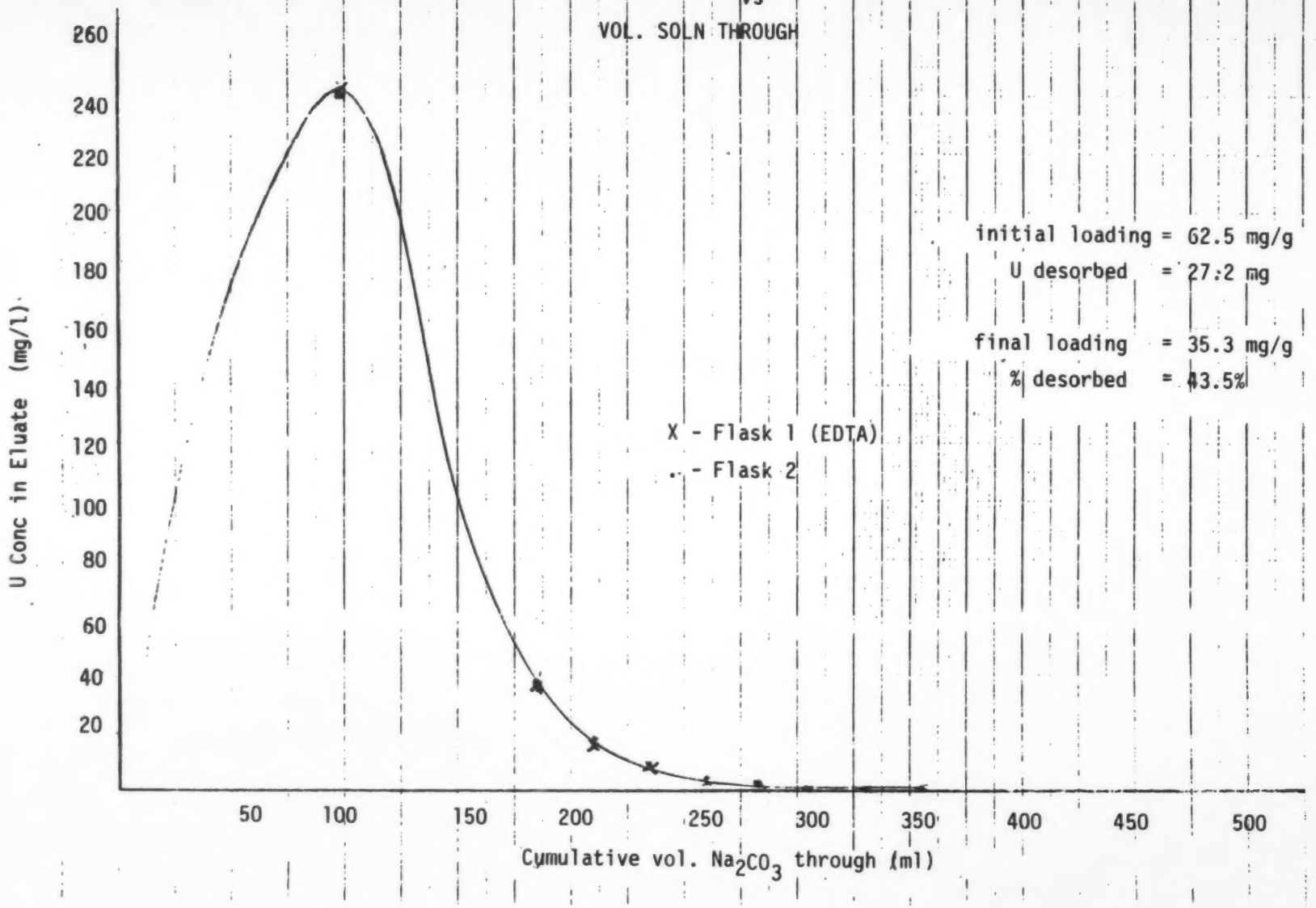


FIGURE 42

INACT. ACTINOMYCETE CONTINUOUS ADSORPTION #2

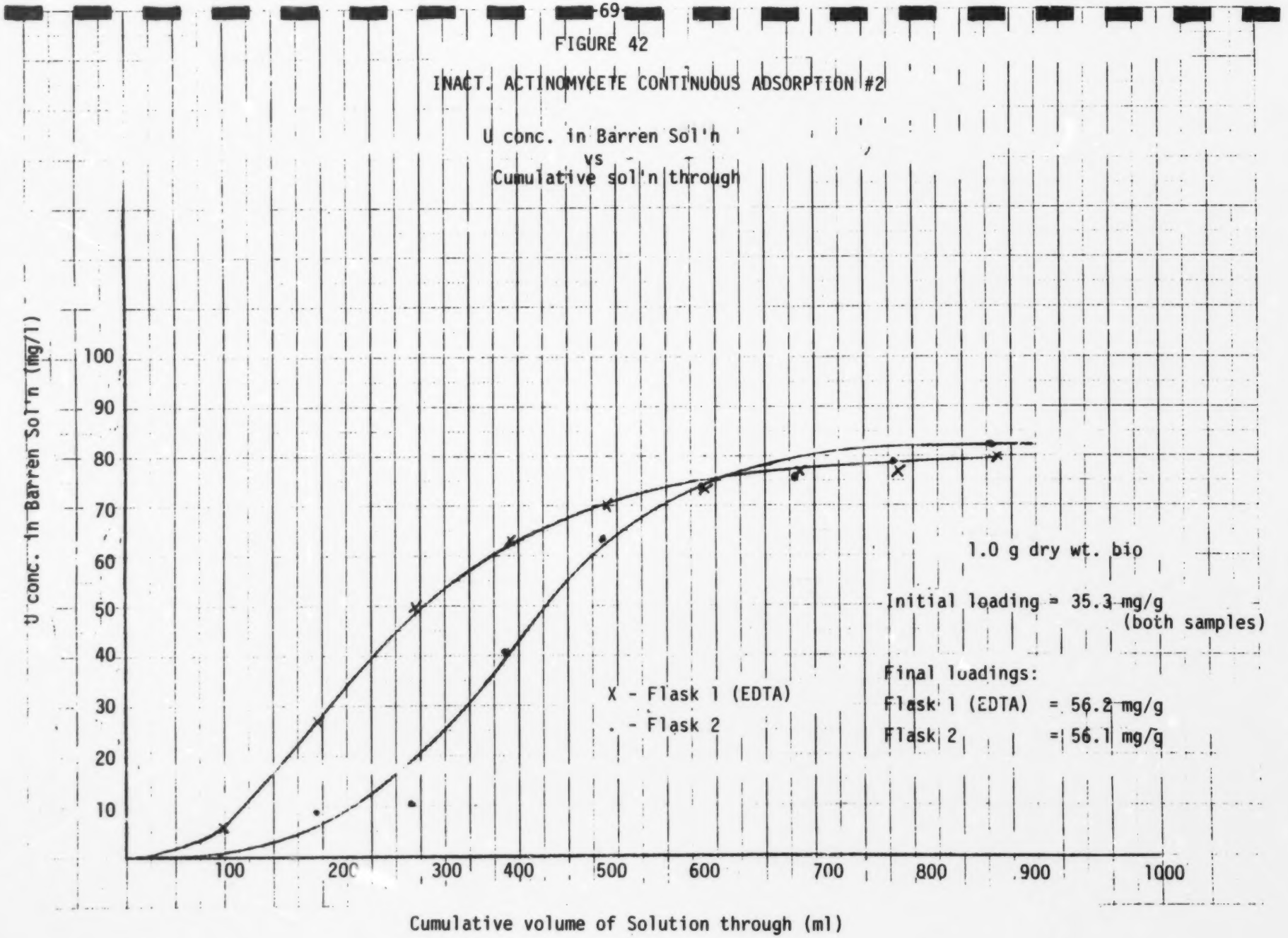


FIGURE 43

INACT ACTINOMYCETE CONTINUOUS DESORPTION #2

U CONC IN ELUATE

VS

Vol. Soln through

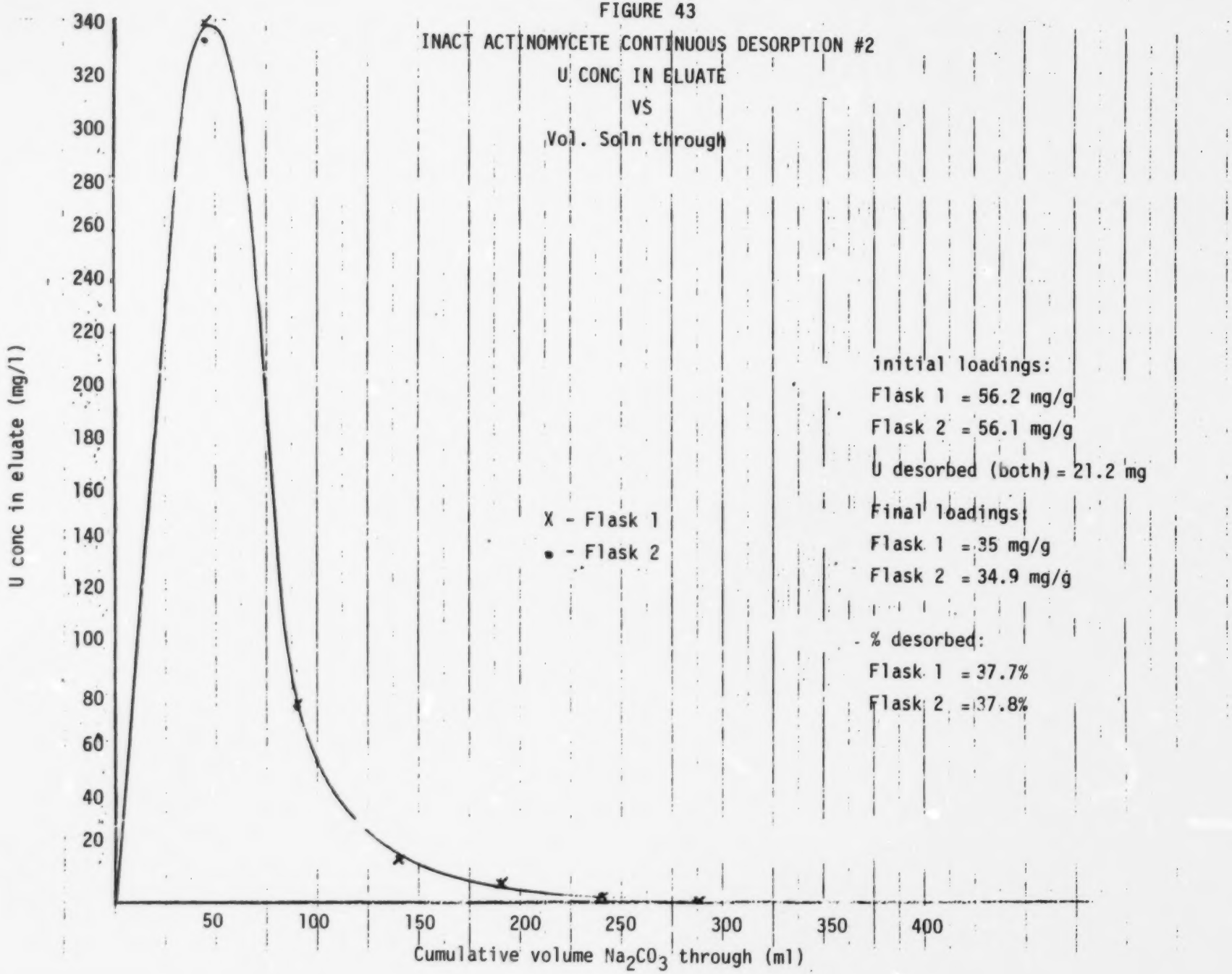


Table 4

Actinomycete Continuous Test
Uranium Balance

Adsorption #1

Samples #1 & 2 - 62.5 mg/g U loading

Desorption #1

Samples #1 & 2 - initial loading = 62.5 mg/g
total desorbed = 27.2 mg
final loading = 35.3 mg/g
% desorbed = 43.5%

EDTA #1

Sample #1 only - no uranium desorbed

Adsorption #2

Sample #1 - initial loading = 35.3 mg/g
final loading = 56.2 mg/g
amount adsorbed = 20.9 mg/g

Sample #2 - initial loading = 35.3 mg/g
final loading = 56.1 mg/g
amount adsorbed = 20.8 mg/g

Desorption #2

Sample #1 - initial loading = 56.2 mg/g
total desorbed = 21.2 mg
final loading = 35.0 mg/g
% desorbed = 37.7%

Sample #2 - initial loading = 56.1 mg/g
total desorbed = 21.2 mg
final loading = 34.9 mg/g
% desorbed = 37.8%

EDTA #2

Sample #1 only - no uranium desorbed

Figure 4

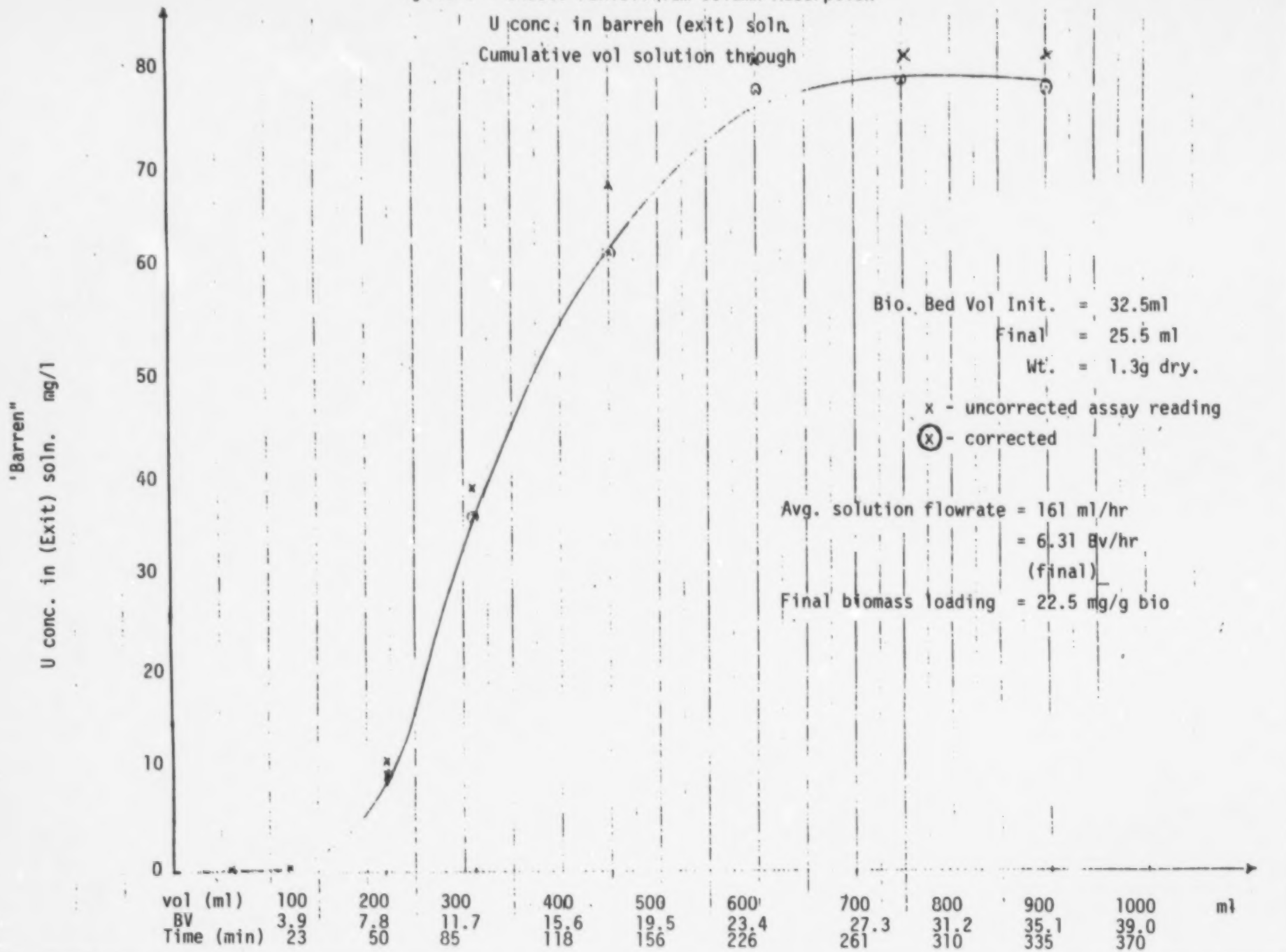

Cycle 1 - Inact. Penicillium Column Adsorption
U conc. in barren (exit) soln.
Cumulative vol solution through
'Barren"
U conc. in (Exit) soln. mg/l
0
10
20
30
40
50
60
70
80
Bio. Bed Vol Init. = 32.5ml
Final = 25.5 ml
Wt. = 1.3g dry.
x - uncorrected assay reading
(x) - corrected
Avg. solution flowrate = 161 ml/hr
= 6.31 Bv/hr
(final)
Final biomass loading = 22.5 mg/g bio
vol (ml) 100 200 300 400 500 600 700 800 900 1000 ml
BV 3.9 7.8 11.7 15.6 19.5 23.4 27.3 31.2 35.1 39.0
Time (min) 23 50 85 118 156 226 261 310 335 370

Figure 45

Cycle 1 - Inact Penicillium Column Desorption

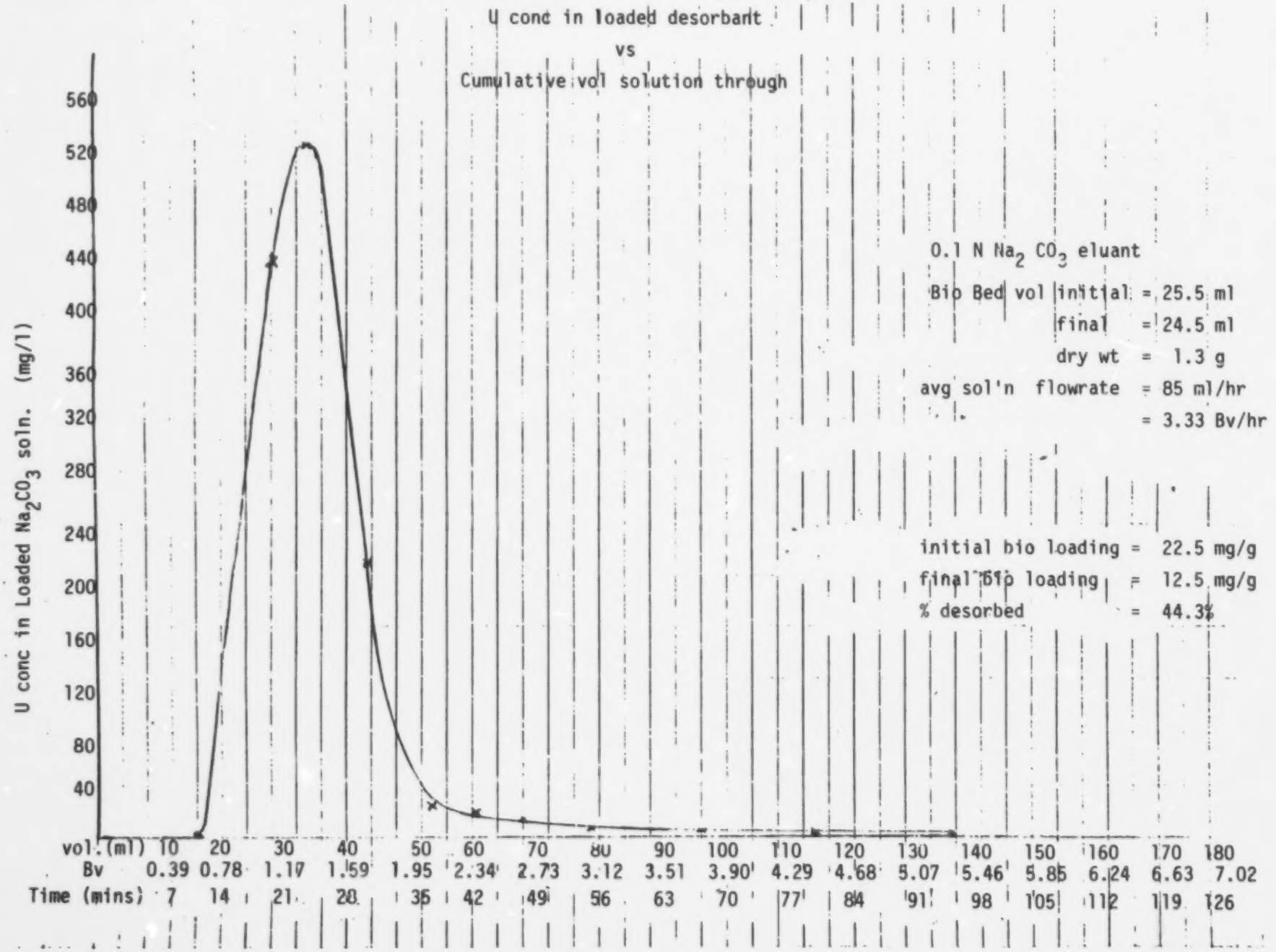


Figure 4

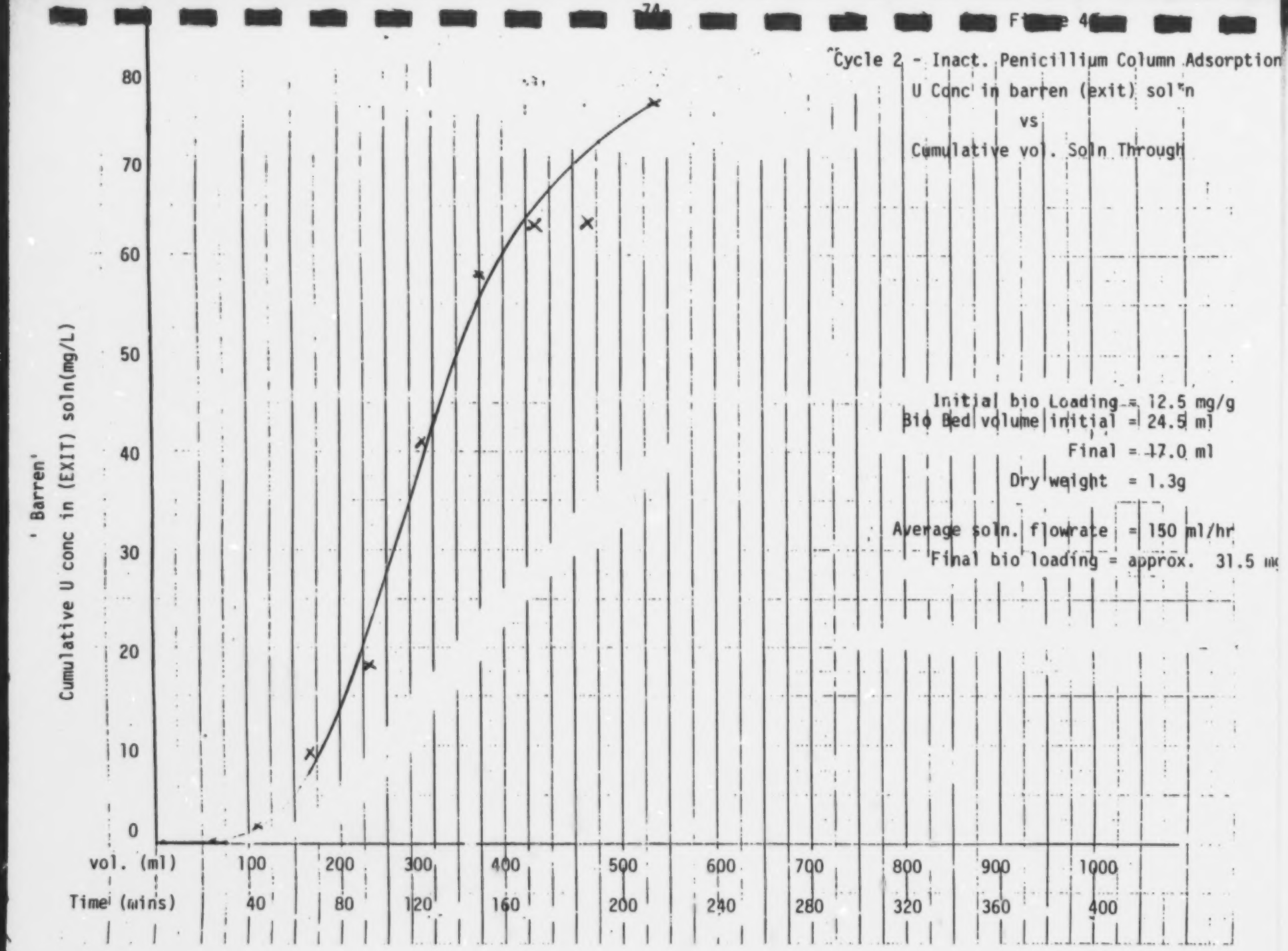

Cycle 2 - Inact. Penicillium Column Adsorption
U Conc in barren (exit) soln
vs
Cumulative vol. Soln Through
Initial bio Loading = 12.5 mg/g
Bio Bed volume initial = 24.5 ml
Final = 17.0 ml
Dry weight = 1.3g
Average soln. flowrate = 150 ml/hr
Final bio loading = approx. 31.5 mg
'Barren' Cumulative U conc in (EXIT) soln(mg/L)
0
10
20
30
40
50
60
70
80
vol. (ml) 100 200 300 400 500 600 700 800 900 1000
Time (mins) 40 80 120 160 200 240 280 320 360 400

FIGURE 47

CYCLE 2 - INACT. Penicillium Column

DESORPTION

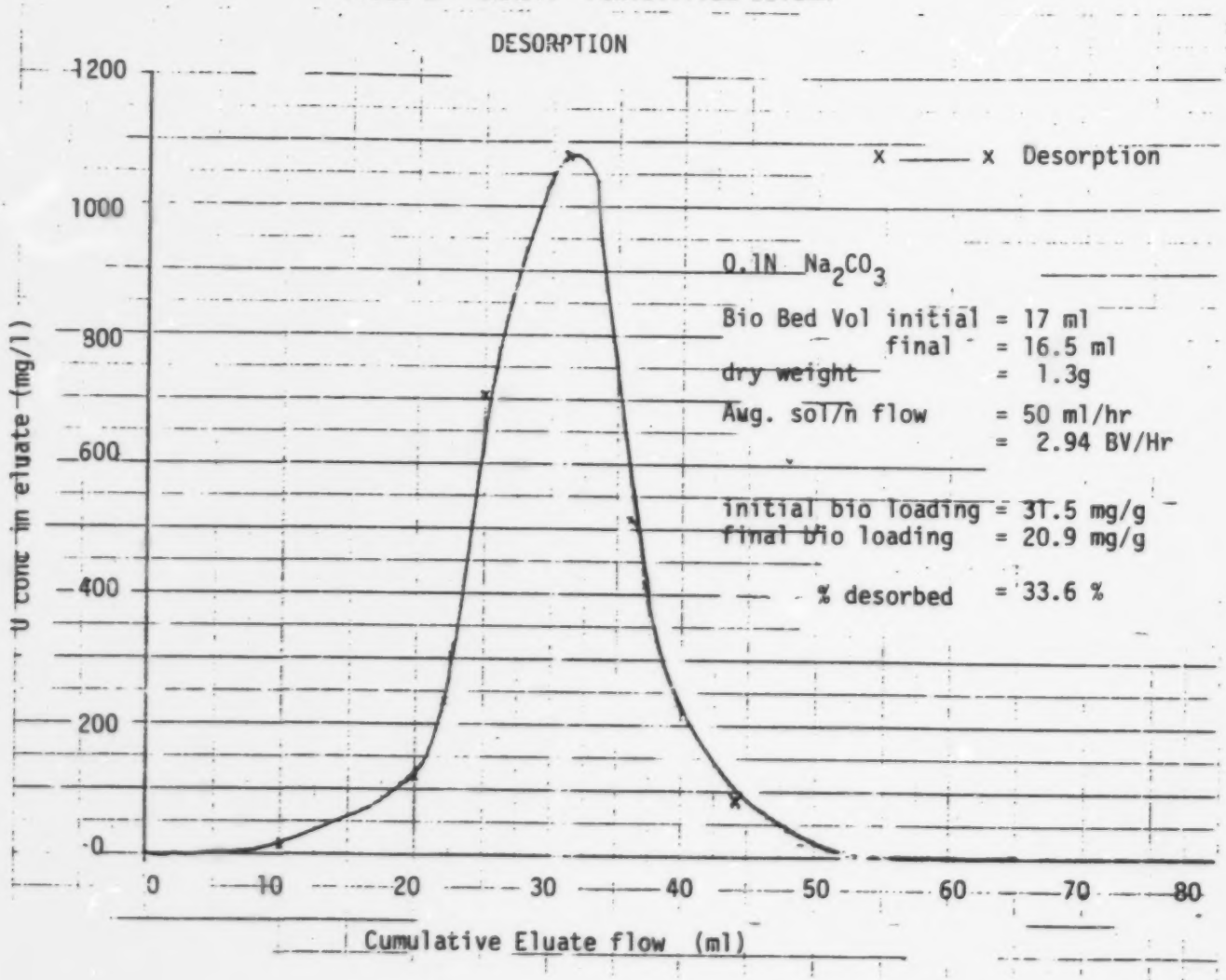


FIGURE 48

CYCLE #3 - INACT.PENICILLIUM

COLUMN DESORPTION

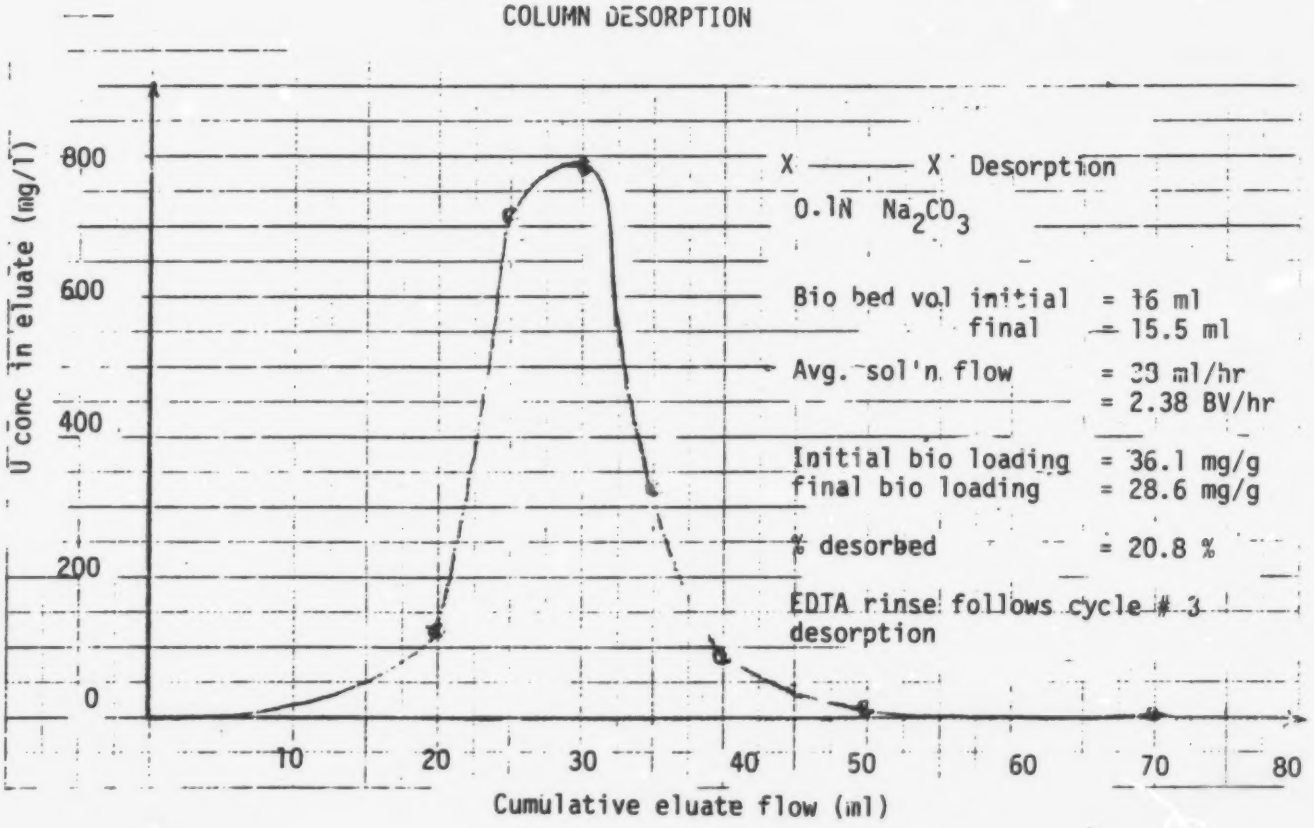


FIGURE 49

INACTIVE PENICILLIUM COLUMN ADSORBTION CYCLES 3 & 4

CUMULATIVE EFFLUENT vs FLOW CONC. (U)

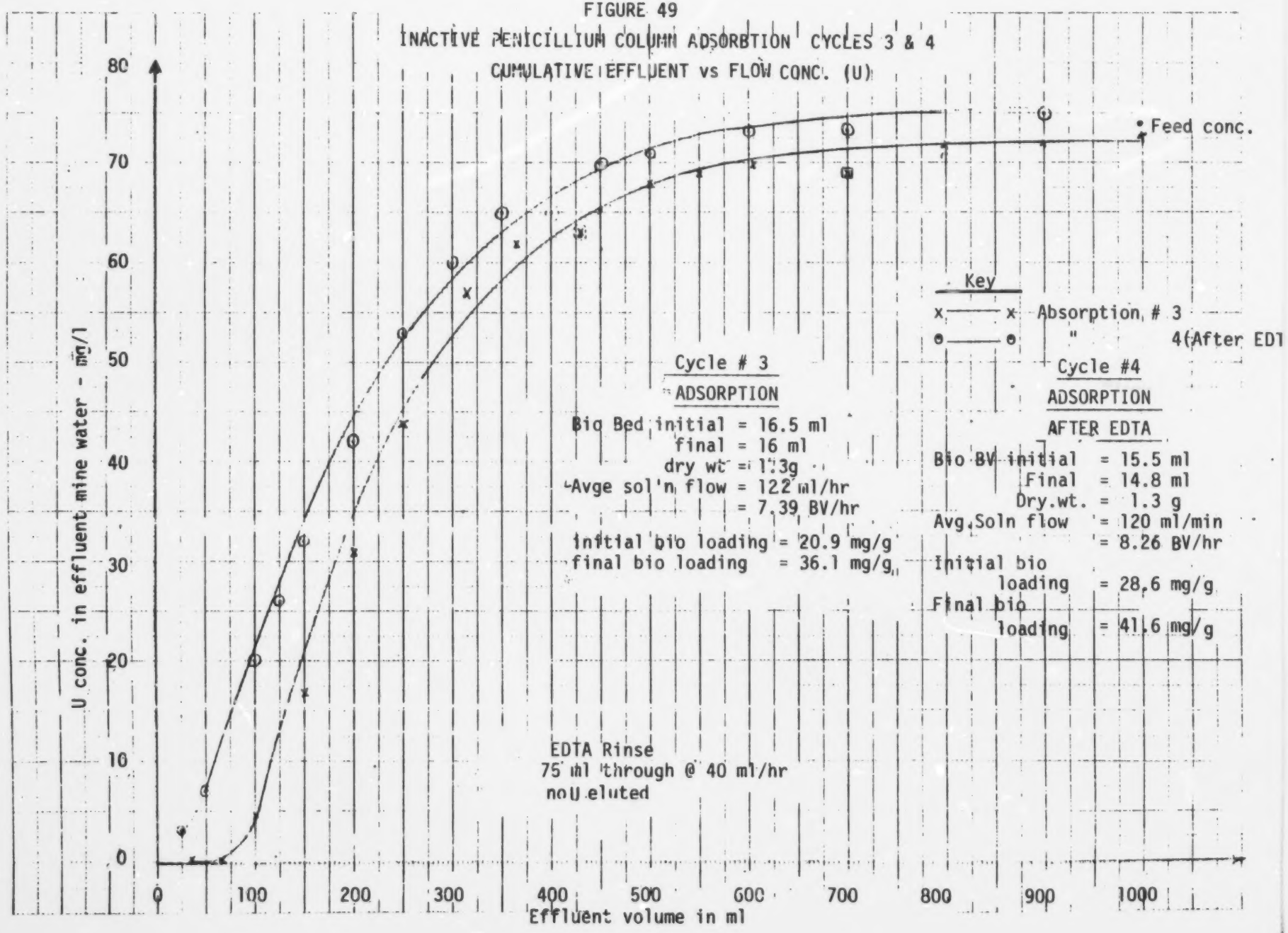
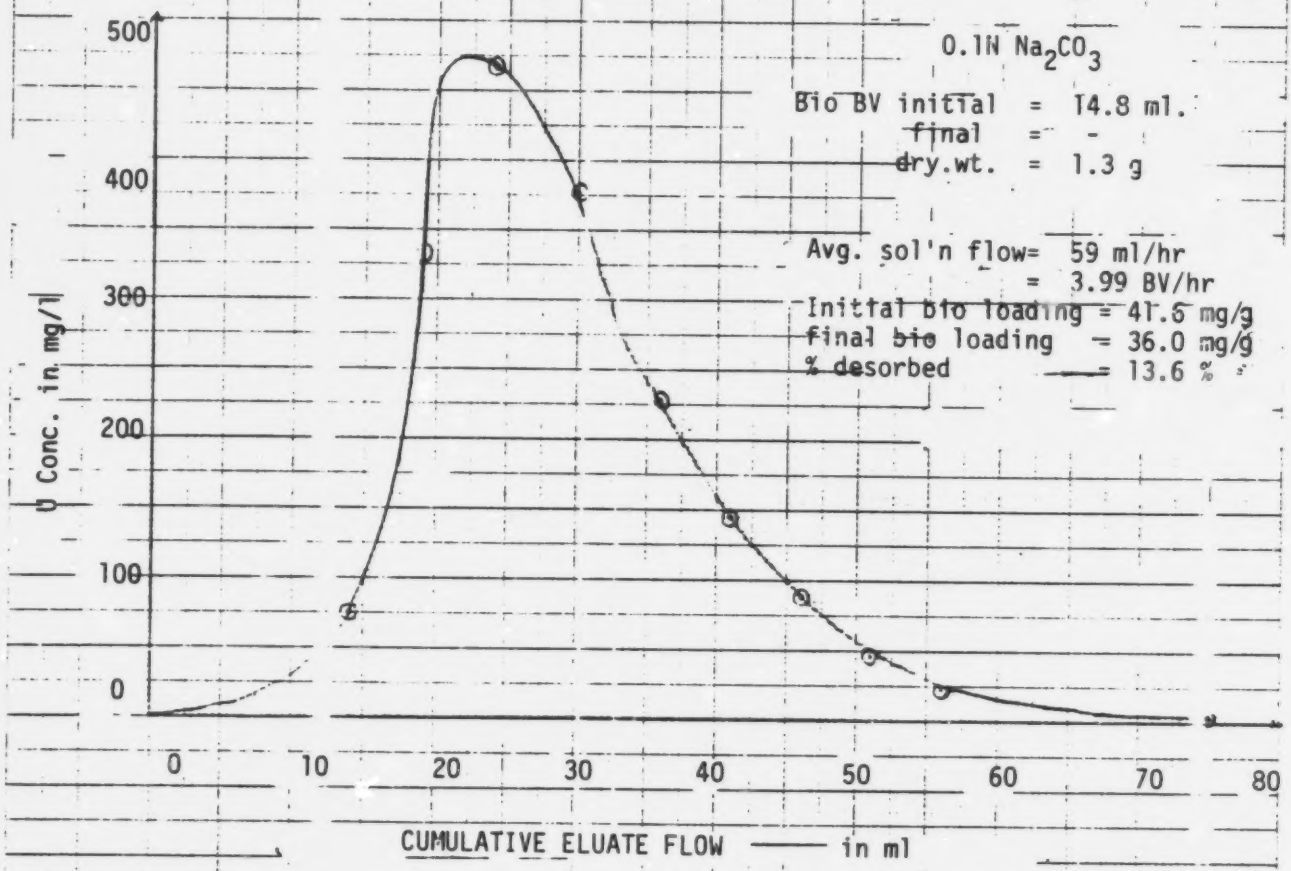


FIGURE 50

Cycle 4 - Inact. Penicillium Column
Desorption



461510

Table 5

Penicillium Column Testing Uranium Balance

Cycle 1 - Adsorption

final loading = 22.5 mg U/g bio.

Cycle 1 - Desorption

initial loading = 22.5 mg/g
final loading = 12.5 mg/g
% desorbed = 44.3%

Cycle 2 - Adsorption

initial loading = 12.5 mg/g
final loading = 31.5 mg/g
amount adsorbed = 19.0 mg/g

Cycle 2 - Desorption

initial loading = 31.5 mg/g
final loading = 20.9 mg/g
% desorbed = 33.6%

Cycle 3 - Adsorption

initial loading = 20.9 mg/g
final loading = 36.1 mg/g
amount desorbed = 15.2 mg/g

Table 5 (Cont'd.)

Cycle 3 - Desorption

initial loading = 36.1 mg/g
final loading = 28.6 mg/g
% desorbed = 20.8%

EDTA Wash

no uranium eluted

Cycle 4 - Adsorption

initial loading = 28.6 mg/g
final loading = 41.6 mg/g
amount adsorbed = 13.0 mg/g

Cycle 4 - Desorption

initial loading = 41.6 mg/g
final loading = 36.0 mg/g
% desorbed = 13.6%

Table 6
Penicillium Size Distributions

A) Before Column Testing

Mesh Size	% Retained	Cum. % Passing
14	96.3	3.7
24	3.3	0.4
48	0.3	0.1
65	0.1	-
-65	-	-
	100.0	

B) After Column Testing

Mesh Size	% Retained	Cum. % Passing
14	79.2	20.8
24	20.3	0.5
48	0.5	-
-48	-	-
	100.0	

FIGURE 51

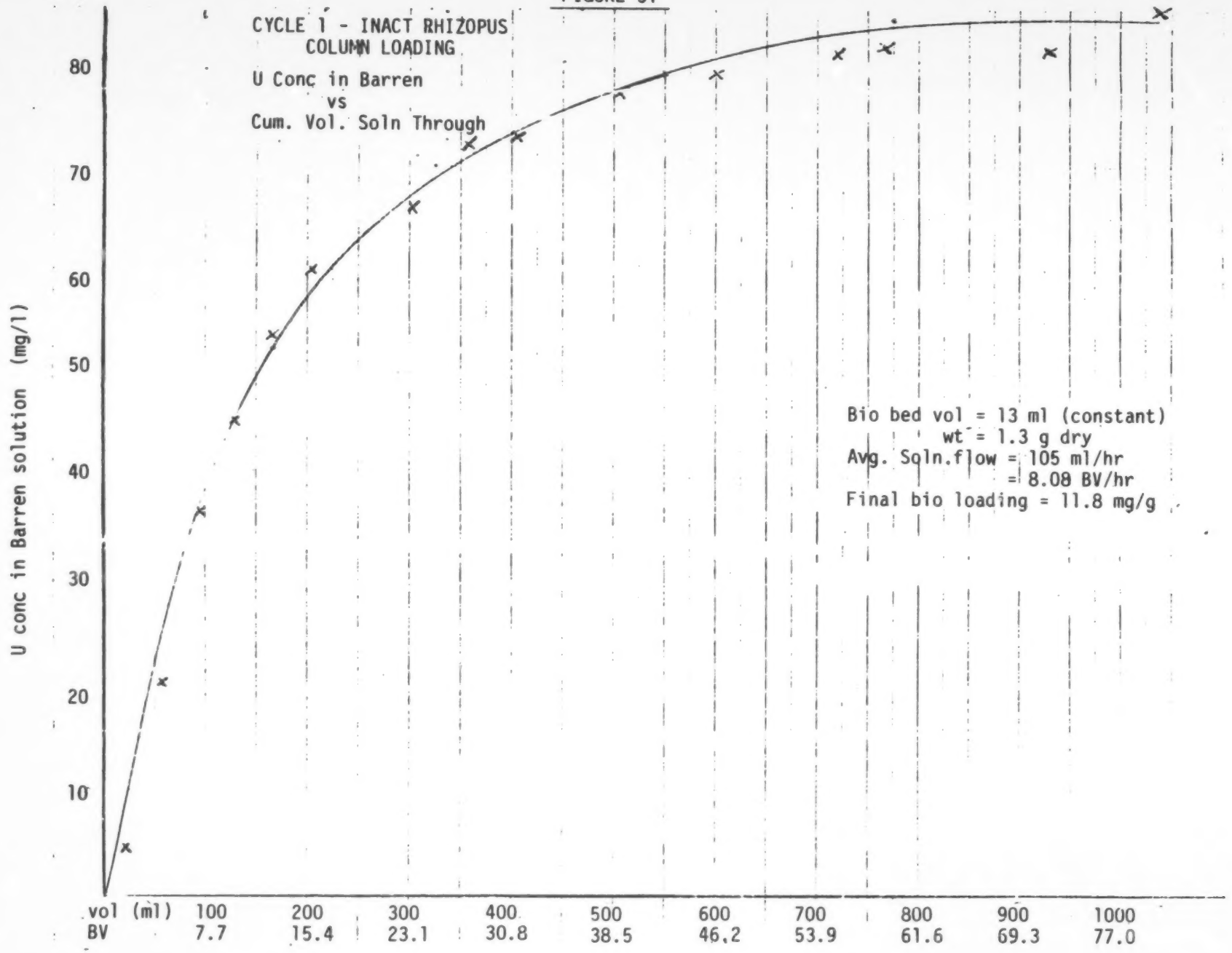
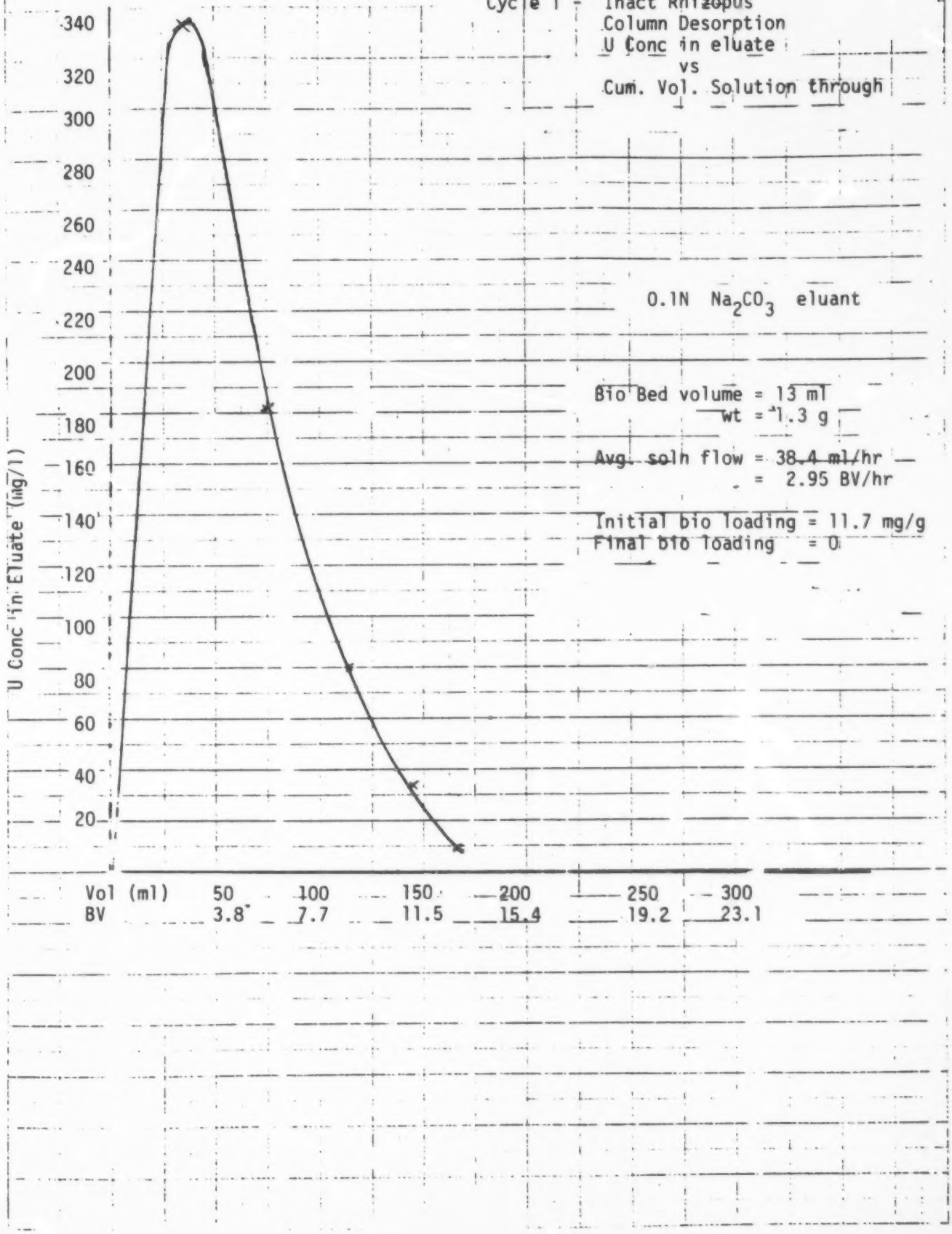

CYCLE 1 - INACT RHIZOPUS
COLUMN LOADING
U Conc in Barren
vs
Cum. Vol. Soln Through
U conc in Barren solution (mg/l)
80
70
60
50
40
30
20
10
Bio bed vol = 13 ml (constant)
wt = 1.3 g dry
Avg. Soln.flow = 105 ml/hr
= 8.08 BV/hr
Final bio loading = 11.8 mg/g
vol (ml) 100 200 300 400 500 600 700 800 900 1000
BV 7.7 15.4 23.1 30.8 38.5 46.2 53.9 61.6 69.3 77.0

FIGURE 52
Cycle 1 - Inact Rhizopus
Column Desorption
U Conc in eluate
vs
Cum. Vol. Solution through



0.1N Na_2CO_3 eluant

Bio Bed volume = 13 ml
wt = 1.3 g

Avg. soln flow = 38.4 ml/hr
= 2.95 BV/hr

Initial bio loading = 11.7 mg/g
Final bio loading = 0

Figure 53

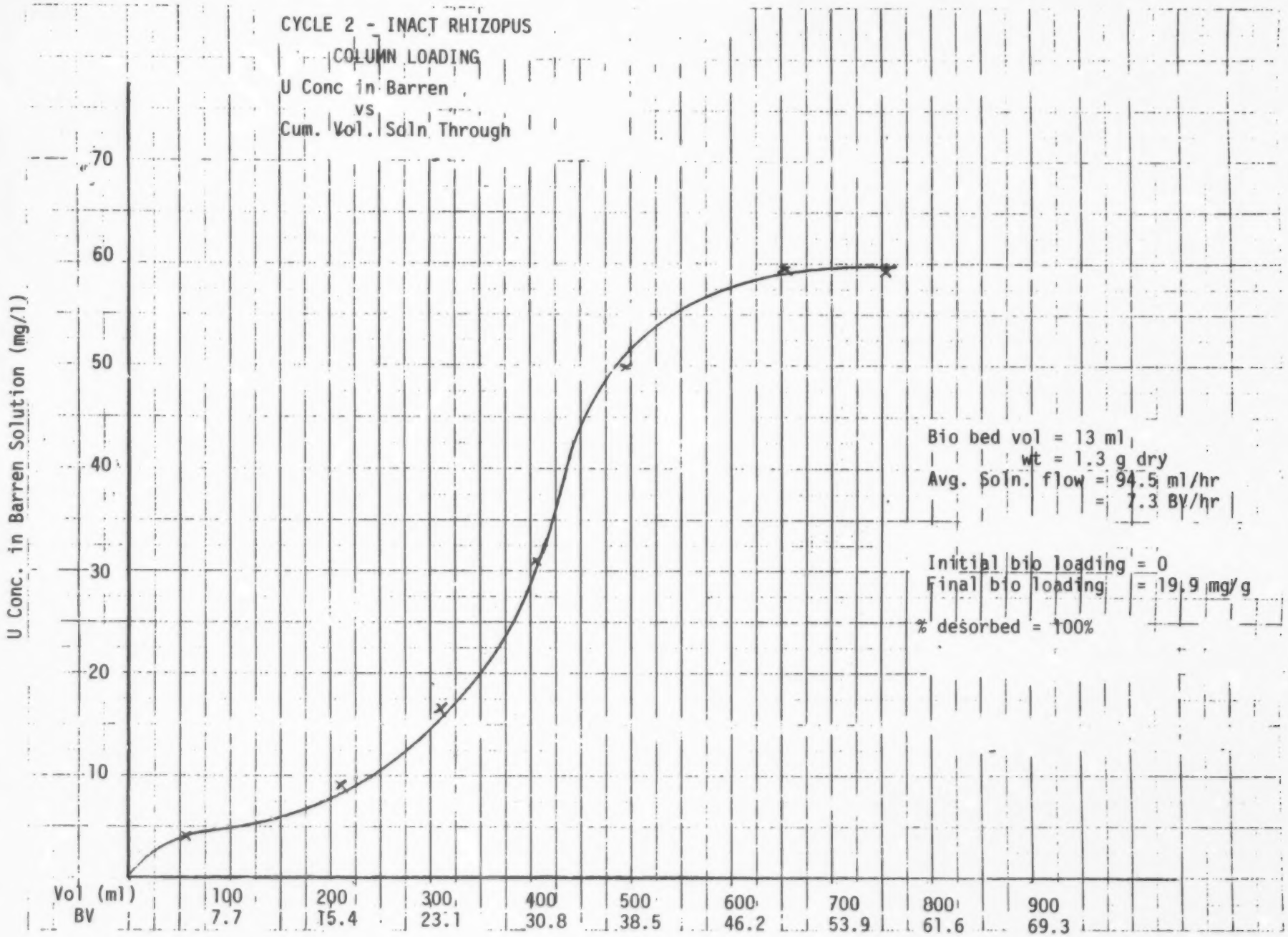

CYCLE 2 - INACT RHIZOPUS
COLUMN LOADING
U Conc in Barren
vs
Cum. Vol. Soln Through
U Conc. in Barren Solution (mg/l)
70
60
50
40
30
20
10
Bio bed vol = 13 ml
wt = 1.3 g dry
Avg. Soln. flow = 94.5 ml/hr
= 7.3 BV/hr
Initial bio loading = 0
Final bio loading = 19.9 mg/g
% desorbed = 100%
Vol (ml)
BV
100
7.7
200
15.4
300
23.1
400
30.8
500
38.5
600
46.2
700
53.9
800
61.6
900
69.3

Figure 54

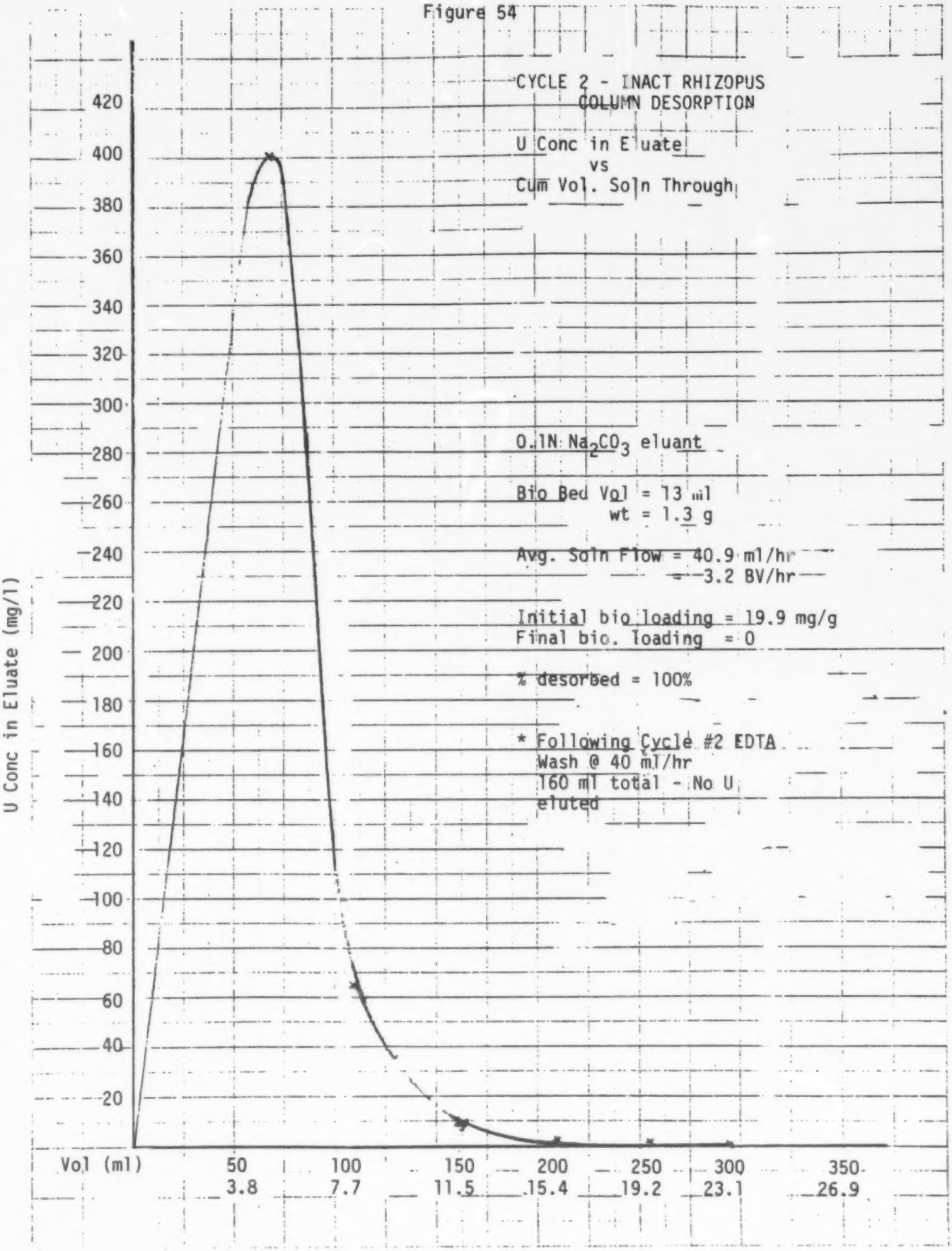

CYCLE 2 - INACT RHIZOPUS
COLUMN DESORPTION
U Conc in Eluate
vs
Cum Vol. Soln Through
0.1N Na_2CO_3 eluant
Bio Bed Vol = 13 ml
wt = 1.3 g
Avg. Soln Flow = 40.9 ml/hr
= 3.2 BV/hr
Initial bio loading = 19.9 mg/g
Final bio. loading = 0
% desorbed = 100%
* Following Cycle #2 EDTA
Wash @ 40 ml/hr
160 ml total - No U
eluted
U Conc in Eluate (mg/l)
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Vol (ml)
50
3.8
100
7.7
150
11.5
200
15.4
250
19.2
300
23.1
350
26.9

Figure 65

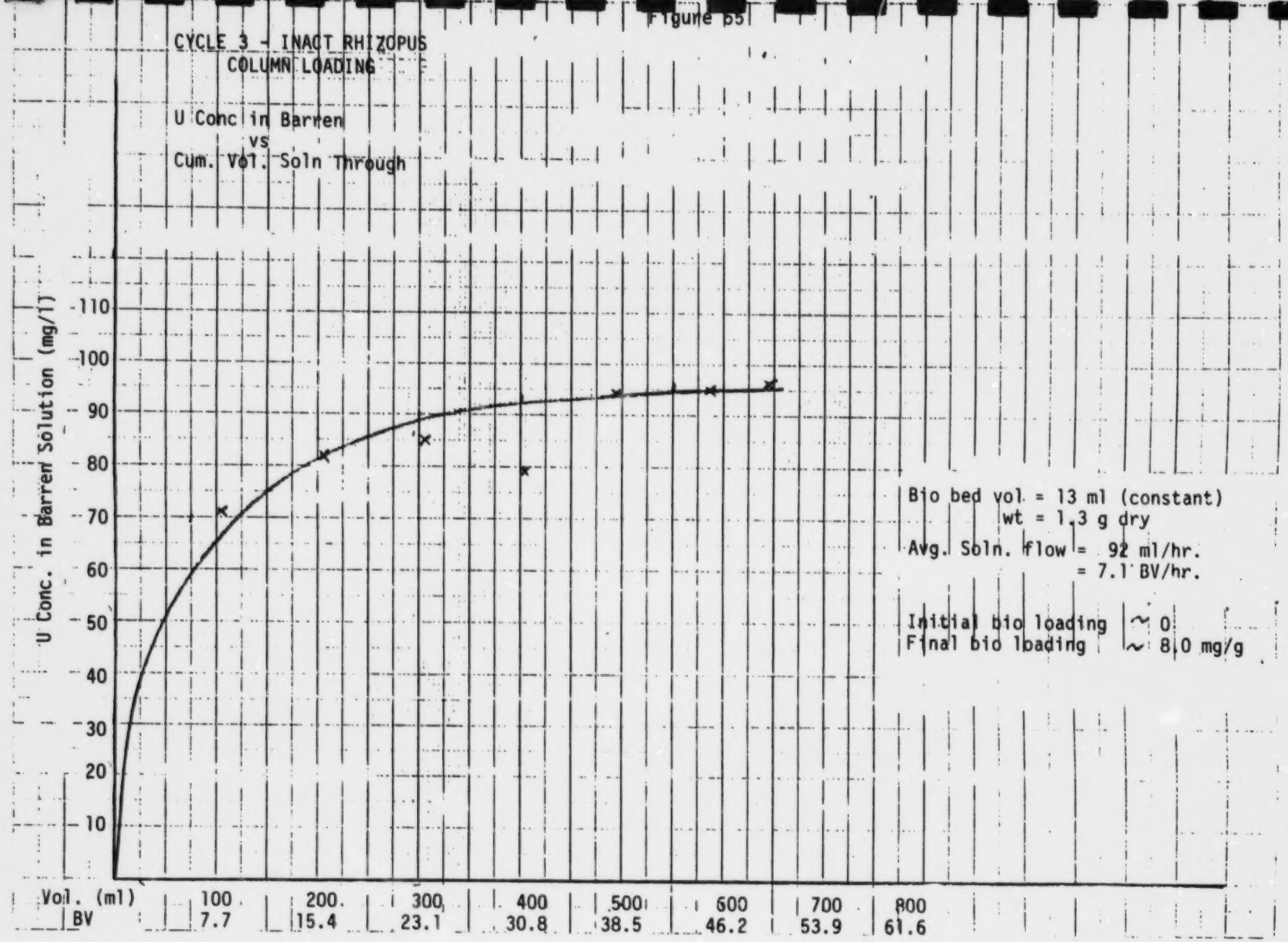
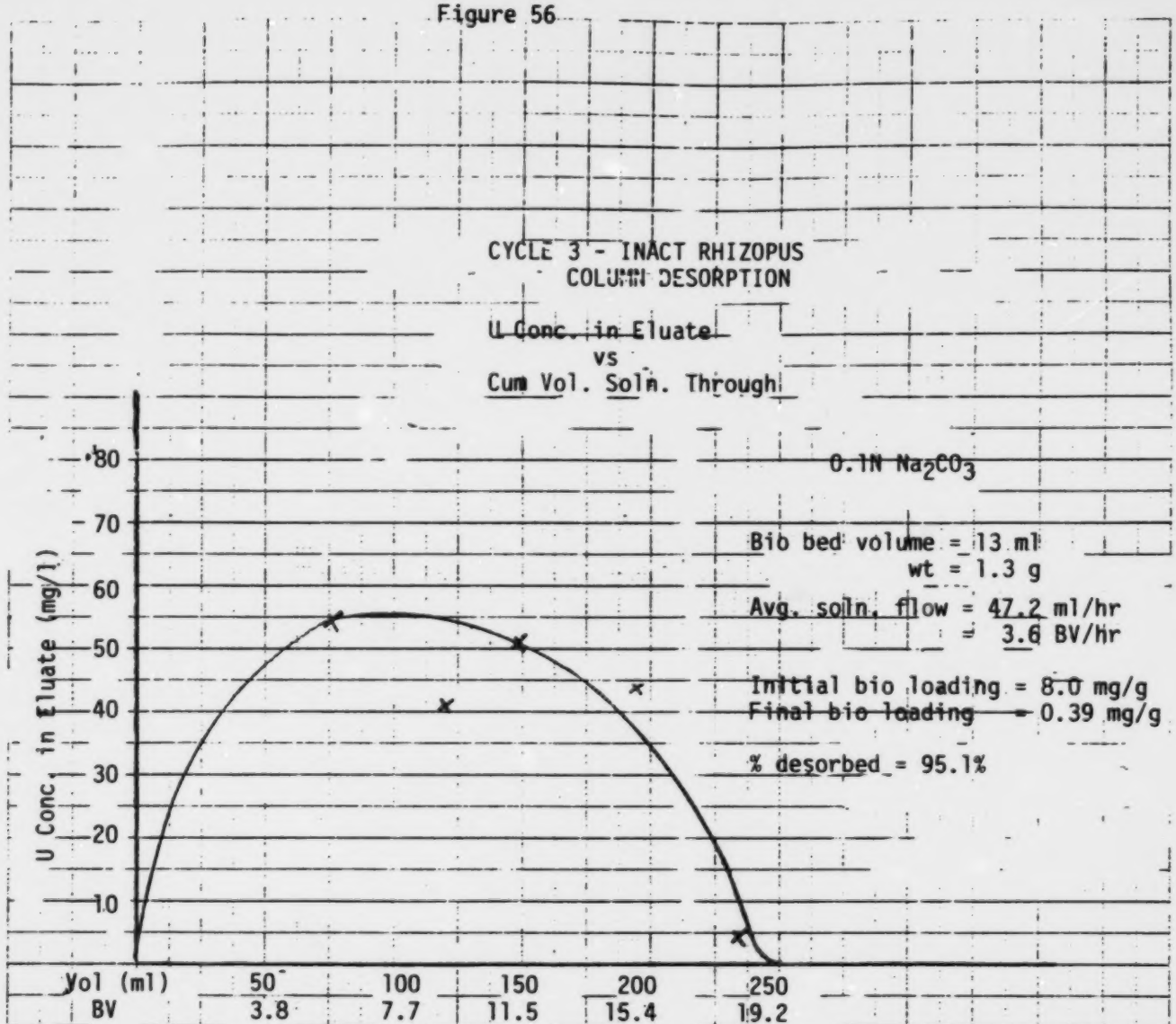

CYCLE 3 - INACT RHIZOPUS
COLUMN LOADING
U Conc in Barren
vs
Cum. Vol. Soln Through
U Conc. in Barren Solution (mg/l)
110
100
90
80
70
60
50
40
30
20
10
Bio bed vol = 13 ml (constant)
wt = 1.3 g dry
Avg. Soln. flow = 92 ml/hr.
= 7.1 BV/hr.
Initial bio loading ~ 0
Final bio loading ~ 8.0 mg/g
Vol. (ml)
BV
100
7.7
200
15.4
300
23.1
400
30.8
500
38.5
600
46.2
700
53.9
800
61.6

Figure 56



461510

Table 7

Rhizopus Column Testing Uranium Balance

Cycle 1 - Adsorption

final loading = 11.8 mg/g

Cycle 1 - Desorption

initial loading = 11.8 mg/g
final loading = 0
% desorbed = 100%

Cycle 2 - Adsorption

initial loading = 0
final loading = 19.9 mg/g
amount adsorbed = 19.9 mg/g

Cycle 2 - Desorption

initial loading = 19.9 mg/g
final loading = 0
% desorbed = 100%

EDTA Wash

no uranium eluted

Table 7 (Cont'd.)

Cycle 3 - Adsorption

initial loading = 0
final loading = 8.0 mg/g
amount adsorbed = 8.0 mg/g

Cycle 3 - Desorption

initial loading = 8.0 mg/g
final loading = 0.39 mg/g
% desorbed = 95.1%

PHASE III REPORT

EVALUATION OF BIOMASSES

1. INTRODUCTION

The results of testwork carried out in Phase II on Denison isolates showed that Penicillium had the best overall performance characteristics.

Testwork carried out on the three biomasses was based on batch tests in shaker flasks and continuous tests in columns (except Actinomycete). The loading and elution results for batch and continuous tests were very different, as illustrated by the following table:

Biomass	Batch Test Performance		Continuous Test Performance	
	Loading	Elution	Loading	Elution
Penicillium	Good	Excellent	Good	Poor
Actinomycete	Good	Good	Excellent	Poor
Rhizopus arrhizus	Moderate	Poor	Moderate	Excellent

The process for the recovery of uranium using biomass is based on the following technical requirements:

i) efficient biomass preparation
ii) efficient loading of the biomass
iii) physical separation of biomass and leach solution
iv) elution of the biomass to produce a high concentration eluate
v) physical separation of the biomass and eluate
vi) (possible) regeneration of the biomass

In view of the above requirements, selection of an appropriate commercial scale process flowsheet must be made on the basis of the physical characteristics and chemical performance of the biomass.

The use of banks of columns for loading and elution, similar to conventional ion exchange systems, satisfactorily addresses the physical handling aspects of the biomasses (except Actinomycete). With columns, the biomass does not have to undergo extensive handling, filtration, etc. Loading and elution cycles are initiated and terminated by simple valve actions.

However, from a chemical standpoint, continuous column operation does not perform very well. The fact that Penicillium elutes well in batch indicates that further optimization work on continuous column operation could result in acceptable elution performance of the biomass. This trend of thought is further supported by the fact that excellent elution results were obtained in continuous column tests with Rhizopus arrhizus.

The conceptual process flowsheet, as shown in drawing No. C1051-FI, was therefore developed on the basis of using continuous column operation for biomass loading and elution. Penicillium was selected as the key biomass for this flowsheet due to its superior overall performance compared to Actinomycete and Rhizopus arrhizus.

The sections which follow deal with the performance of each of the three biomasses with reference to the above conceptual flowsheet.

2. PENICILLIUM

2.1 FLOWSHEET DEVELOPMENT

2.1.1 pH Adjustment

The pregnant leach solution from the stopes has a natural pH of 2. Testwork showed that the uranium loading performance of Penicillium is much greater at pH 4. A pH adjustment step should therefore be introduced to raise the pH of the pregnant solution by lime addition. This in turn causes iron to be precipitated out of solution. Facility therefore has to be provided to remove the iron precipitate before the solution is fed to the biomass loading section. The precipitate should be thickened, filtered and washed in order to minimize losses of uranium (with the iron precipitate).

2.1.2 Biomass Loading and Elution

Loading and elution tests were performed on Penicillium using both agitated tanks and continuous columns. Varying results for elution were obtained. However, loading characteristics were almost equal in both cases.

Agitated Tanks

The use of agitated tanks for loading and elution of the biomass, either continuously or batchwise, requires the use of filters and/or screens to separate the biomass and the solutions between stages. Vacuum and pressure filters could be used successfully for this duty. However, the voluminous nature of the biomass and the large amount of solution retained with the biomass cake will require a large filtration area and a high wash ratio to maintain an acceptable soluble loss.

These factors will make filtration an expensive step. Also, the agitation of the biomass in the tanks, and the movement of the biomass between the different stages will result in increased losses due to attrition.

Columns

The use of columns for loading and elution of the biomass is ideal as the material is retained within the column. Consequently, losses of biomass due to agitation and transportation do not occur. The challenge in using columns is to obtain an acceptable flowrate through the biomass bed. Acceptable solution flowrates were obtained in the testwork due to the pelletized nature of the Penicillium species. Another advantage of this system is that the equipment used is similar to the ion exchange systems which are widely used for uranium recovery, particularly by Denison Mines and Rio Algom in Elliot Lake.

The conceptual flowsheet was therefore based on the use of columns for loading and elution.

2.1.3 Selection of Eluant

Sodium carbonate, sodium chloride and sulfuric acid were all tested as eluants for Penicillium. Sodium carbonate was selected as the eluant in this flowsheet because it was the most effective of the three tested. It is also acceptable environmentally as the only ions introduced underground would be sodium and carbonate.

2.1.4 Yellowcake Precipitation

In uranium mills which use carbonate leach to extract uranium from high acid-consuming ores, caustic soda is used to precipitate uranium as sodium diuranate. The precipitation reaction is slow and retention times of the order of 6 to 12 hours are required. A quantitative precipitation of uranium is difficult, so an excess of caustic soda is usually provided to obtain good precipitation recoveries. The precipitation is performed at a temperature of 70 - 80°C and often some yellowcake is recycled to improve the efficiency. The yellowcake is generally thickened prior to filtration. The filter cake is then dried.

2.1.5 Eluant Carbonation

The addition of caustic soda in the yellowcake precipitation circuit provides the make-up to the eluant. However, the excess caustic soda must be carbonated before the eluant is returned to the elution circuit. Carbon dioxide from burner off-gases is usually used for carbonation of solutions. This operation can be carried out either in flotation cells or in a packed tower. Flotation cells were chosen for this flowsheet.

2.1.6 Biomass Fermentation

The testwork showed that batch aerobic fermentation worked very well for preparation of *Penicillium* and that adding the air via a draft tube gave acceptable agitation of the biomass. Inactivated biomass was also shown to have better loading characteristics than viable biomass. Consequently, it was decided to use a batch aerobic fermenter and to inactivate the biomass before use in the circuit.

2.2 CONCEPTUAL FLOWSHEET

The conceptual flowsheet developed for Penicillium is shown in Drawing No. C1050-FI. The following description applies to this flowsheet.

The pregnant leach solution from the stopes has a natural pH of 2. Lime is therefore added to raise the pH to 4. The pH adjustment is carried out in two agitated tanks in series with the discharge from the second tank sent to the iron precipitate thickener. The underflow from the thickener is sent to vacuum drum filters where the iron precipitate is filtered and washed before being discharged from the circuit. The drum filtrate is recycled to the thickener. The thickener overflow is then stored in the pregnant solution reservoir ready for feeding to biomass loading.

The biomass loading and elution section consists of six banks of columns, each bank having four columns in series. Each bank operates independently of the others and has its own automatic sequence controller. The sequence of operation of each bank of columns is as follows:

i) The pregnant solution is passed through three columns in series and the uranium is progressively removed from the solution and loaded on to the biomass. The solution leaving the final column is barren of uranium and is stored in the barren leach solution reservoir ready for recycle to the leaching stopes.

ii) When the biomass in the lead column is fully loaded with uranium, the column is taken out of the circuit by switching valves. The valving is adjusted so that the column that was second in the series becomes the lead column and the final column becomes the second one. A column of freshly eluted biomass is then added to the end of the series.

iii) The column with the loaded biomass is eluted by circulation of solution containing sodium carbonate through the biomass bed. A split elution technique can be used to increase the concentration of the pregnant eluate which is fed to the yellowcake precipitation section. With this technique, the first half of the eluant is pumped through the column of biomass and sent to the yellowcake precipitation circuit. The second half is then pumped through the column and stored ready for the next cycle. When the biomass has been eluted, the column is then held ready for introduction into the loading series at the end of the next cycle.

The pregnant eluate is fed to two yellowcake precipitation tanks in series, where yellowcake is precipitated by the addition of sodium hydroxide. The discharge from the yellowcake precipitation tanks is sent to the yellowcake thickener. The thickener underflow is then sent to the mill for further treatment. The thickener overflow contains free sodium hydroxide and therefore has to be carbonated prior to recycle to the elution circuit. Carbonation is carried out in a bank of flotation cells where the solution is contacted with carbon dioxide from burner off-gases. The solution discharge from the flotation cells is then stored ready for use in the elution operation.

Fresh biomass to replace losses from the system is prepared in two aerobic batch fermenters which operate independently. Cultured biomass is fed to one of the fermenters and then nutrients are added. The fermentation takes place at ambient temperature and atmospheric pressure. Air is added through a draft tube, which produces a gentle agitation of the biomass. The retention time for fermentation of the biomass is 96 hours. The tank contents are then heated to 80°C for 20 minutes in order to inactivate the biomass. The biomass is then filtered before being fed to the loading/dilution columns as required to replace any losses.

All the equipment in the flowsheet can be located underground close to the bacterial leaching areas, with the exception of the yellowcake precipitation circuit which would be located on surface in the mill.

2.3 DESIGN CRITERIA

The preliminary design criteria developed for Penicillium are shown in Table 8. The criteria have been selected from testwork results in Phase II and typical uranium milling practice.

2.4 CULTURE REQUIREMENTS AND COST OF NUTRIENTS

The testwork in Phase II showed that the dilute nutrient broth/glucose medium recommended by Dr. R.G.L. McCready afforded satisfactory growth of the Penicillium species. As noted previously, the optimum pH for growth of the biomass was found to be 4.3, although growth will occur at lower pH.

Accordingly, a culture protocol is recommended whereby the culture is inoculated into dilute nutrient broth/glucose medium pH 4.3 (sterilized by autoclaving at 100 kPa for 20 minutes) prior to adjustment of the pH to 4.3.

The airlift mode of operation (aeration rate 2L/min on 0.36 vvm) affords the desirable pelletized form of growth of the Penicillium. The incubation temperature should be ambient (23°C).

The medium as used in this study contained:

Bacto Beef Extract	(Difco)	- 0.3 g/L
Bacto Peptone	(Difco)	- 0.5 g/L
Glucose (BDH)		- 5.0 g/L

This medium has been costed based on the following quoted prices (May 20, 1986):

Bacto peptone	- 10 kg	-	$867.00
Bacto Beef Extract (Technical)	- 500 g	-	61.25
Glucose (USP, anhydrous)	- 50 kg	-	175.00

Based on these prices the medium cost is estimated to be $97.60/1000 L. At a volumetric productivity of 0.45 g dry Penicillium biomass /L/80 hr. incubation period, this would be equivalent to $.217/g dry biomass.

This price should be regarded as the "worst possible" value since cheaper industrial sources of glucose, peptone, trace nutrients etc. should be investigated. At present, since these alternatives have not been evaluated as nutrients, no attempt has been made to base the cost calculation on the current quoted costs for potential industrial substitutes.

Additional information is required as to which nutrients are growth limiting. This will influence the selection of the optimum mode of operation of the fermentation (i.e. batch versus continuous or fed batch, etc.). The goal will be to ensure that no nutrient is growth limiting but also that large excesses of nutrients will not persist in the fermentation broth at the end of the fermentation and hence require expensive waste treatment processes for disposal.

2.5 EASE OF SCALE-UP

The effects of different factors that impact on the scale-up of the conceptual flowsheet are discussed below.

2.5.1 Mass and Energy Balance Considerations

No special scale-up considerations are evident with regard to mass and energy balances for this flowsheet. The loading and elution operations are performed at ambient temperature and the only requirement for heating and cooling are for yellowcake precipitation and for the inactivation of the biomass.

2.5.2 Process Control

The process control required for this flowsheet is straight forward. For the iron removal step, the operation will be controlled by the pH in the iron precipitation tanks together with conventional controls on the thickener and filters. The loading/elution columns will be controlled automatically using sequence controllers which will be similar to those used in ion exchange systems for water treatment and uranium recovery. For yellowcake precipitation, controls will consist of conventional temperature and flow regulators. For fermentation, a batch operation will be used which simplifies the control of the fermenters.

2.5.3 Liquid/Solid Contacting

The use of banks of columns for the biomass loading and elution operations reduces the potential problems associated with scale-up of this flowsheet. The size of the columns chosen should be similar to those used for uranium recovery or water treatment. It is then simply a matter of specifying the number of banks of columns required. One question that should be resolved during pilot plant operation is whether the biomass can withstand the pressure required to overcome the resistance of three columns in series or whether a separate feed pump is required for each column. For the fermenters, special consideration will have to be given in scale-up to the design of the draft tube and the method of air addition. The other areas of the flowsheet do not present any special scale-up problems as they consist of conventional unit processes which have been used successfully elsewhere.

2.5.4 Liquid/Solid Separation

The use of columns for biomass loading and elution removes the need for liquid/solid separation of the biomass and solutions between operations. The only liquid/solid separation required in the flowsheet is for the recovery of biomass from the nutrient broth, the removal of the iron precipitate from the pregnant solution, and the thickening of the yellowcake. The last two operations are conventional and do not present any scale-up problems. The filtration of biomass is less well known. However, major problems in scale-up are not anticipated, although care will have to be taken in selecting the best filter for this duty.

2.5.5 Materials Handling

The handling of solutions and of yellowcake slurries is well established and does not present any scale-up problems. The area that is less well known in the mining industry is in the handling of biomass. However, the biomass is only found in the fermenters and in the loading/elution columns and so handling should not present any major problems.

2.5.6 Types of Equipment and Materials of Construction

As described earlier, the equipment used in the flowsheet is conventional and does not present any major scale-up problems. The acidic nature of the pregnant solution requires that all equipment in the pH adjustment and biomass loading/elution circuits be made of acid resistant materials such as rubber lined carbon steel, stainless steel or FRP. In the yellowcake precipitation and eluant carbonation circuits, the operations are carried out at high pH so carbon steel can be used as well as FRP.

The fermenters will require stainless steel construction to minimize the generation of contaminants.

2.5.7 Generation of Contaminants and Desired Products

The operation of the fermentation step under the conditions experienced in the mining industry does present some potential problems in scale-up of this flowsheet. The possibility of generating contaminants in the biomass must be guarded against with great care. However, this problem can be overcome by instituting special operating procedures for the fermenters.

2.5.8 Nutrient Requirements

The preparation and addition of nutrients does not present any special problems in the scale-up of this flowsheet.

2.6 MAJOR TECHNICAL PROBLEMS

The major technical problems related to the conceptual flowsheet are as follows:

i) Poor elution performance of the Penicillium. Extensive bench and pilot scale testwork is required to achieve acceptable elution performance of the biomass. The fact that batch elution is excellent indicates that there is room for improvement on the commercial scale.

ii) Ability of the Penicillium to withstand the conditions experienced in the circuit. Pilot scale testing will be necessary to establish the life of the biomass through repeated cycles of loading and elution. Also, the testwork should check on the physical losses of biomass from the columns, and on the physical performance of the biomass under the pressures experienced in columns of this type.

Losses of ion exchange resins are very low and resin life is long. Therefore, for biosorption to have any chance of replacing conventional ion exchange, it must have satisfactory performance in these areas and superior performance in other areas, such as loading and elution.

3. ACTINOMYCETE

3.1 FLOWSHEET DEVELOPMENT

3.1.1 General

Actinomycete in the leach solution has the appearance of a colloidal suspension, very similar to glue. The tests carried out in Phase II on Actinomycete showed that columns could not be used for loading and elution as acceptable solution flow could not be achieved. Consequently, the flowsheet developed for Penicillium would not be applicable for use with Actinomycete.

The only area of the flowsheet that will require modification is the biomass loading and elution circuit. The other areas will be the same as described in section 2.0.

3.1.2 Liquid/Solid Contacting

Testwork carried out in batch agitated tank type systems showed uranium loading on Actinomycete to be similar to Penicillium, but the elution characteristics were not as good. Consequently agitated tanks could be used for loading and elution. However for continuous operation, filters and/or screens are necessary to separate the biomass and solution between stages. Due to the physical nature of the Actinomycete, the use of filters and screens is a problem and so batch operation of the tank would be preferred.

3.1.3 Liquid/Solid Separation

Based on observations during the test program, it would be difficult to recommend a system or flowsheet that would be viable for the use of Actinomycete on commercial scale, because liquid/solid separation would be a major problem. In a process of this nature, it is necessary to load the biomass through contact with leach solutions, and then elute it using a much smaller volume of eluant, thereby achieving a high concentration solution for uranium recovery. In order to achieve this, the biomass has to be separated from the leach solution and the eluant during different stages of the process cycle. The cost of liquid/solid separation for Actinomycete would be prohibitive on the commercial scale because its filtration characteristics are very poor.

3.2 DESIGN CRITERIA

The preliminary design criteria developed for Actinomycete are shown in Table 9. The criteria have been selected from test results in Phase II and typical uranium milling practice.

3.3 CULTURE REQUIREMENTS AND COST OF NUTRIENTS

As in the case of the Penicillium, Actinomycete grows well in the dilute nutrient broth/glucose medium. Tests showed that supplementation of this medium with tryptone enhanced the growth of the organism. However, the biomass was extremely difficult to recover by filtration and hence the medium was used without the addition of tryptone. The initial pH of the sterilized medium was pH 4.3, but it decreased naturally during the growth of the organism.

The medium must be sterilized by autoclaving at 100 kPa for 20 minutes prior to the adjustment of the pH to 4.3. Although stirred fermenters were used in Phase II of the study, it is recommended that the airlift concept using an aeration rate of 2L/min. (or 0.36 vvm) be used. The Actinomycete attaches tenaciously to surfaces, including impellers etc. and it is considered that in the airlift mode this problem may be minimized. The incubation should be carried out at ambient temperature.

The costs of the medium and the recommendations for additional studies are as described for Penicillium. The Actinomycete grows well under a continuous batch mode of operation and might benefit from use of a continuous flow process to maximize biomass productivity per unit of limiting weight nutrient (most probably tryptone).

It is estimated that based on a nutrient cost of $97.60/1000 L and the biomass yield of 0.3 g dry biomass /L/12 hr. incubation period, the production cost of the biomass is $.325/g dry biomass. This is higher than in the case of the Penicillium but the growth rate of the Actinomycete is better.

3.4 MAJOR TECHNICAL PROBLEMS

Liquid/solid separation problems with Actinomycete makes the biomass unsuitable for use on the commercial scale. Further process development work on this biomass would not be recommended unless the structure can be altered to create acceptable liquid/solid separation characteristics.

4. RHIZOPUS ARRHIZUS

4.1 FLOWSHEET DEVELOPMENT AND CONCEPTUAL FLOWSHEET

Loading and elution tests were performed on Rhizopus arrhizus using both batch agitated tanks and continuous columns. Comparable results were obtained with both methods. However, elution of Rhizopus arrhizus was much better in the continuous column mode of operation.

The relative merits of agitated tanks and columns have been discussed in Section 2.0 (Penicillium). Since Rhizopus arrhizus has similar handling and liquid/solid separation characteristics to Penicillium, the conceptual flowsheet (C1051-FI) developed for Penicillium would be directly applicable.

The only major difference is that during the biomass preparation stage, it is necessary to homogenize the Rhizopus arrhizus by some form of blending/shredding action. Rhizopus tends to form into very large, fluffy pellets which require shredding to increase the surface area in order to achieve suitable loading and elution characteristics.

4.2 DESIGN CRITERIA

The preliminary design criteria for Rhizopus arrhizus are shown in Table 10. The criteria have been selected from test results in Phase II and typical uranium milling practice.

4.3 CULTURE REQUIREMENTS AND COST OF NUTRIENTS

The culture procedures, the medium and the cost data are as described for Penicillium. The pH used (4.3) is not necessarily optimum for this organism but was selected in order to standardize the growth conditions for each biomass. Based on a previous study, the growth of this organism is enhanced by supplementation of the medium with tryptone.

4.4 EASE OF SCALE-UP AND MAJOR TECHNICAL PROBLEMS

The scale-up considerations for Rhizopus are similar to those described for Penicillium in Section 2.5.

Pilot plant testing is necessary for Rhizopus arrhizus to determine the ability of the biomass to withstand the conditions experienced in the circuit. Further work on improving the loading characteristics is also recommended.

Table 8
Preliminary Design Criteria for Penicillium

Area 01 - Fermentation:	
No. of Fermenters	2
Fermenter Type	Aerobic/Airlift
Method of Operation	Batch
Retention Time	80 Hours
Solids Content (Glucose)	5 g/L
Operating Temperature	Ambient
Operating Pressure	Atmospheric
Biomass Loss in the Adsorption-Desorption Process	10%
Air Addition Rate	2L/min x Fermenter Volume
Inactivation Temperature	80°C
Biomass Yield	0.45 g (Dry) biomass/L Fermenter Capacity
Area 02 - Biomass Filtration:	
Type of Filter	Belt Filter or Equivalent
Area 03 - pH Adjustment:	
Leach Solution Feed Rate	100 m^3/hr
Precipitation Method	Lime Addition ($Mg(OH)_2$ preferred
pH of Leach Solution Feed	2
pH in Precipitation Vessel	4
Operating Temperature	Ambient
No. of Stages	2
Retention Time Per Stage	30 Minutes
Liquid/Solid Separation	Thickener/Clarifier + Drum Filter
Area 04 - Biomass Loading:	
Leach Solution Feed Rate	100 m^3/H
Leach Solution Assay	100 mg U/L
Net Biomass Loading	25 mg U/g Dry Biomass
Method of Loading	Columns
No. of Stages	6 Parallel Stages with 4 Columns in Series Per Stage
Leach Solution:Biomass Ratio	30:1 (by volume)

Table 8 - (Cont'd.)

Area 05 - Biomass Elution:	
Type of System	Common to Biomass Loading
Eluant	Sodium Carbonate
Retention Time/Stage	15 Minutes
% Uranium Recovery in Elution	95% (based on batch tests) 40% (Based on column tests)
Elution Technique	Split Elution
Area 06 - Yellowcake Precipitation:	
Method	Caustic Soda
No. of Stages	2
Retention Time/Stage	6 Hours
Area 07 - Yellowcake Dewatering:	
Type of System	Thickener
Underflow Solids Density	30% Solids
Area 09 - Carbonation:	
Method	Flue Gasses from Combustion
Type of System	Flotation Cells

Table 9
Preliminary Design Criteria for Actinomycete

Area 01 - Fermentation	
No. of Fermenter	2
Fermenter Type	Aerobic/Airlift
Method of Operation	Continuous/Batch
Retention Time	12 Hours
Solids Content (Glucose)	5 g/L
Operating Temperature	Ambient
Operating Pressure	Atmospheric
Biomass Loss in the Adsorption-Elution Process	10%
Air Addition Rate	2 L/min x Fermenter Volume
Inactivation Temperature	80 - 85° C
Biomass Yield	0.3 g (Dry) biomass/L Fermenter/Day
Area 02 - Biomass Filtration:	
Type of Filter	Undetermined Due to Very Poor Liquid/Solid Separation Characteristics
Area 03 - pH Adjustment:	
Leach Solution Feed Rate	100 m^3/hr
Precipitation Method	Lime Addition ($Mg(OH)_2$ Preferred)
pH of Leach Solution Feed	2
pH in Precipitation Vessel	4
Operating Temperature	Ambient
No. of Stages	2
Retention Time Per Stage	30 Minutes
Liquid/Solid Separation	Thickener/Clarifier + Drum Filter
Area 04 - Biomass Loading:	
Leach Solution Feed Rate	100 m^3/hr
Leach Solution Assay	100 mg U/L
Net Biomass Loading	25 mg U/g Dry Biomass
Method of Loading	Undetermined
Leach Solution:Biomass Ratio	Undetermined
Area 05 - Biomass Elution:	
Type of System	Undetermined
Eluant	Sodium Carbonate
% Uranium Recovery in Elution	90% (based on batch tests) 40% (based on continuous)

Table 9 (Cont'd.)

Area 06 - Yellowcake Precipitation:	
Method	Caustic Soda
No. of Stages	2
Retention Time/Stage	6 Hours
Area 07 - Yellowcake Dewatering:	
Type of System	Thickener
Underflow Solids Density	30% Solids
Area 09 - Carbonation:	
Method	Flue Gasses From Combustion
Type of System	Flotation Cells

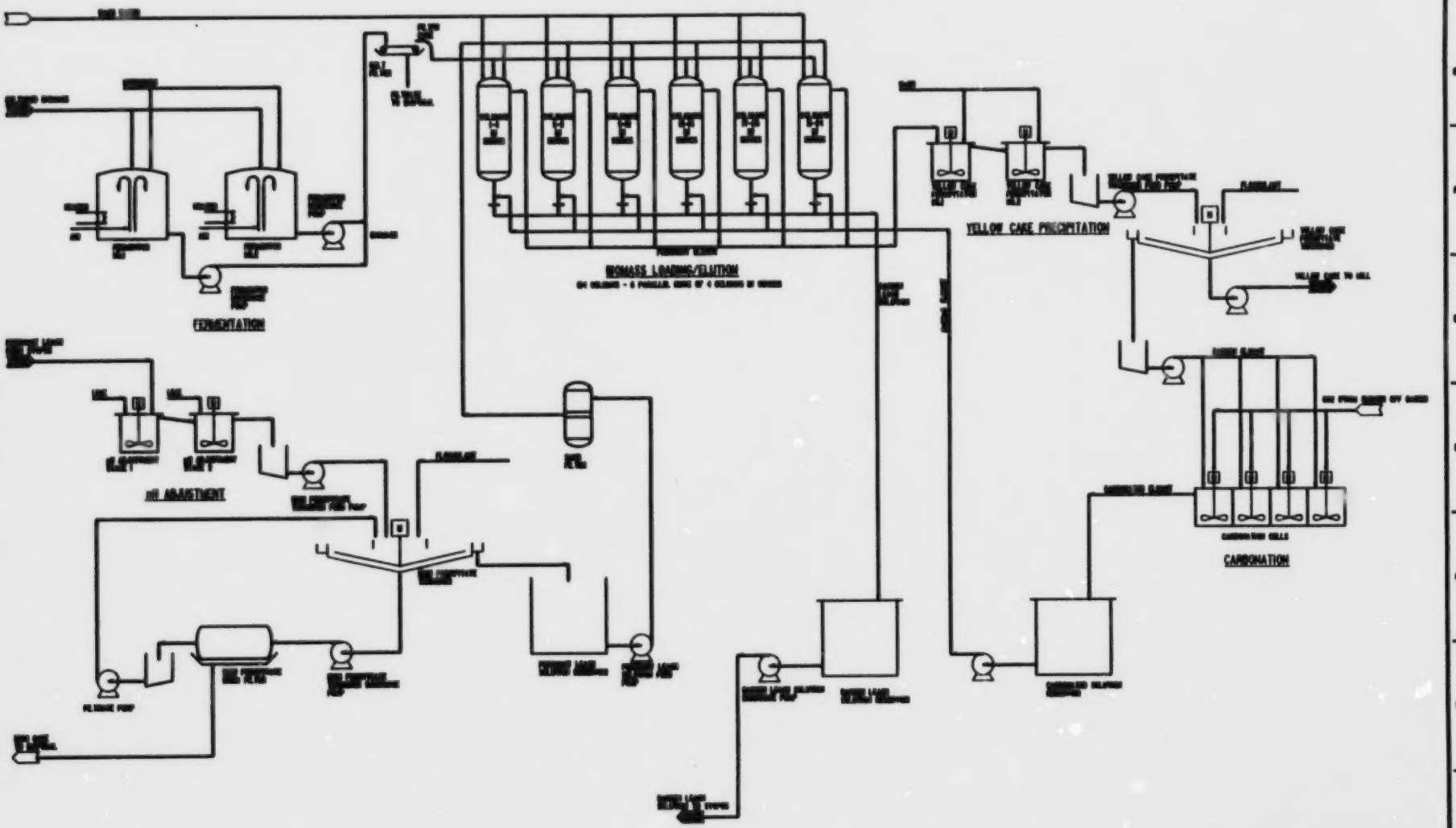
Table 10
Preliminary Design Criteria for Rhizopus arrhizus

Area 01 - Fermentation	
No. of Fermenters	2
Fermenter Type	Aerobic/Airlift
Method of Operation	Batch
Retention Time	80 Hours
Solids Content (Glucose)	5 g/L
Operating Temperature	Ambient
Operating Pressure	Atmospheric
Biomass Loss in the Adsorption-Elution Process	10%
Air Addition Rate	2 L/min x Fermenter Volume
Inactivation Temperature	80 - 85° C
Biomass Yield	0.45 g (Dry) biomass/L Fermenter Capacity
Biomass Preparation (Homogenization)	Shredding to produce smaller particle size
Area 02 - Biomass Filtration:	
Type of Filter	Belt Filter or Equivalent
Area 03 - pH Adjustment:	
Leach Solution Feed Rate	100 m^3/hr
Precipitation Method	Lime Addition ($Mg(OH)_2$ Preferred)
pH of Leach Solution Feed	2
pH in Precipitation Vessel	4
Operating Temperature	Ambient
No. of Stages	2
Retention Time Per Stage	30 Minutes
Liquid/Solid Separation	Thickener/Clarifier + Drum Filter
Area 04 - Biomass Loading:	
Leach Solution Feed Rate	100 m3/hr
Leach Solution Assay	100 mg U/L
Biomass Loading	13 mg U/g* Dry Biomass
Method of Loading	Columns
No. of Stages	6 Parallel Stages with 4 columns in series per stage

* this could go as high as 25 depending on dispersion of biomass.

Table 10 (Cont'd.)

Area 05 - Biomass Elution:	
Type of System	Common to Biomass loading
Eluant	Sodium Carbonate
Retention Time/Stage	60 Minutes
% Uranium Recovery in Elution	35% (based on batch tests) 100% (based on continuous)
Elution Technique	Split Elution
Area 06 - Yellowcake Precipitation:	
Method	Caustic Soda
No. of Stages	2
Retention Time/Stage	6 Hours
Area 07 - Yellowcake Dewatering:	
Type of System	Thickener
Underflow Solids Density	30% Solids
Area 09 - Carbonation:	
Method	Flue Gasses From Combustion
Type of System	Flotation Cells



ADM
Archer Daniels Midland

APPENDIX

RAW DATA

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 15

Conditions:

Temp = 23°C
Initial pH = 2.0
Initial emf = + 520

Other: Head = 93 mg/l V
10 mg/l Y
79 mg/l Th

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.075	91	9.7	2.0	2.7	0.4
0.375	91	10	2.0	0.53	-
0.75	85	9.6	1.95	1.07	0.05
1.50	81	9.6	1.95	0.8	0.03

Comments:

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 14.3

Conditions:

Temp = 24°C
Initial pH = 2.95
Initial emf = +400

Other: Head = 96.8 mg/l U
12.7 mg/l Y
40 mg/l Fe

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	101	13	2.85	-	-
0.5	83	13	2.95	2.8	-
1.0	44	12	3.00	10.6	0.7
2.0	6.5	9.6	2.20	4.5	0.16

Comments:

Biomass lumpy.

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 14.3

Conditions:

Temp = 24°C

Initial pH = 4.25

Initial emf = + 340

Other: Head = 80 mg/l U
12.4 mg/l Y
4.4 mg/l Fe

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	59	13	4.15	21.0	-
0.5	8.2	10.5	4.20	14.4	0.38
1.0	2.5	8.1	4.20	7.8	0.43
2.0	0.95	7.9	3.85	3.95	0.23

Comments

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 15

Conditions:

Temp = 24°C

Initial pH = 1.80 - 1.85

Initial emf = N/A

Other: High Fe^{3+}
Head = 130 mg/l U
137 mg/l Y
5210 mg/l Fe

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g	bio [Fe] mg/g
0.1	96.8	14.7	5210	1.85	6.2	-	-
0.5	102.1	15.8	5000	1.95	0.18	-	42.0
1.0	85.3	13.2	4895	1.85	1.8	0.05	31.5
2.0	75.8	11.6	4842	1.80	1.4	0.1	18.4

Comments:

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 16.4

Conditions:

Temp = 24°C

Initial pH = 2.45

Initial emf = N/A

Other: High SO_4 Head = 95.8 mg/l U, 12.6 mg/l Y, 29 g/l SO_4

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	93.7	11.6	2.50	2.1	1.0
0.5	85.3	10.3	2.45	2.1	0.5
1.0	87.4	11.2	2.45	0.8	0.14
2.0	80.0	10.4	2.50	0.8	0.11

Comments

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 16.4

Conditions:

Temp = 24°C

Initial pH = 1.95

Initial emf = N/A

Other: High PO_4^{3-} Head = 97.9 mg/l U, 13.7 mg/l Y

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	94.7	13.7	1.80	3.2	-
0.5	93.7	13.7	1.85	0.8	-
1.0	73.7	11.6	1.70	2.4	0.21
2.0	67.4	11.6	1.85	1.5	0.10

Comments

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 18.03

Conditions:

Temp = 24°C

Initial pH = 1.75

Initial emf = N/A

Other: High Ca^{2+} Head = 94.7 mg/l U, 12.6 mg/l Y, 470 mg/l Ca

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	90.5	12.6	1.80	4.2	-
0.5	87.4	12.6	1.85	1.5	-
1.0	77.9	12.6	1.70	1.7	-
2.0	68.4	11.6	1.85	1.3	0.2

Comments

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 16.0

Conditions:

Temp = 24°C

Initial pH = 1.75

Initial emf = N/A

Other = high TOC (0.2 g of 2:1 Fuel Oil:Grease)

Head = 93 mg/l U
11 mg/l Y

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	93	10.8	1.85	-	0.2
0.5	83	10.1	1.85	2.0	0.18
1.0	73	9.9	1.80	2.0	0.11
2.0	63	9.8	1.80	1.5	0.06

Comments

Control 120 min

U = 93 mg/l Y = 11 mg/l

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 18.3

Conditions:

Temp = 12°C

Initial pH = 2.05

Initial emf = N/A

Other: Head = 91 mg/l U
12.2 mg/l Y

100 ml soln.

biomass dry wt. (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g
0.1	91	12.1	2.00	-	0.1
0.5	83	11.7	2.05	1.6	0.1
1.0	76	11.0	2.05	1.5	0.12
2.0	63	10.4	2.00	1.4	0.09

Comments

Equilibrium Adsorption

Biomass = Actinomycete inactive grown at pH 2.3 % solids = 11.5

Conditions:

Temp = 24°C
Initial pH = 2.1
Initial emf = + 420

Other: High TSS* = 110 mg/l
Head = 103 mg/l U
13.7 mg/l Y

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	%U ADS	%Y ADS
0.1	103	14.4	2.1	+400	0	-	0	-
0.5	94	14.5	2.1	+420	1.8	-	8.7	-
1.0	68	10.6	2.1	+400	3.5	0.31	34.0	22.6
2.0	70	12.3	2.1	+400	1.7	0.07	32.0	10.2

Comments:

* TSS adjusted with acid washed ground Denision mill tailings.
- acid wash dilute H_2SO_4 (150 ml/l) at 20% solids for 1 hour.
- rinse with distilled water @ 10:1 wash ratio.

Equilibrium Adsorption

Biomass = Actinomycete inactivated

% solids = 18.00

Conditions:

Temp = 22.5°C

Initial pH = 2.15

Initial emf = +410

Other: Head = 117.9 mg/l U
15.2 mg/l Y

biomass grown at pH = 2.3

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	%U ADS	%Y ADS
0.1	120.0	14.5	2.15	+465	-	0.7	-	4.61
0.5	113.6	14.5	1.90	+615	0.86	0.14	3.65	4.61
1.0	113.6	14.5	1.90	+590	0.43	0.07	3.65	4.61
2.0	96.8	14.3	1.90	+590	1.06	0.045	17.90	5.92

Comments:

Actinomycetes grown at pH = 2.3
Mine water as received
Low weight filter quickly, 1.0 g weights are slow to filter.

Equilibrium Adsorption

Biomass = Actinomycete inactive grown at pH 2.3 % solids = 13.21

Conditions:

Temp = 23°C
Initial pH = 2.95
Initial emf = + 390

Other: Head = 104.2 mg/l U
13.4 mg/l Y
65.3 mg/l Fe
biomass grown at pH = 2.3

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g	%U ADS	%Y ADS
0.5	86.3	11.2	46.3	2.60	3.58	0.44	17.18	16.42

Comments:

Mine water adjusted to pH = 3 with saturated NaOH solution
Biomass grown at pH = 2.3

Equilibrium Adsorption

Biomass = Actinomycete inactive grown at pH 2.3 % solids = 13.21

Conditions:

Temp = 23.5°C
Initial pH = 4.05
Initial emf = + 273

Other: Head = 81.1 mg/l U
10.6 mg/l Y
0.6 mg/l Fe
Biomass grown at pH 2.3

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	pH sol	bio [U] mg/g	bio [Y] mg/g	%U ADS	%Y ADS
0.5	33.7	9.5	0.6	3.55	9.48	0.22	58.45	10.38

Comments:

Mine water adjusted to pH = 4 with saturated NaOH solution
Biomass grown at pH = 2.3

Shaker Flask Adsorption Rate

Biomass = Actinomycete inactivated % solids = 18.3

Conditions:

Temp = 24°C Other = Head = 112 mg/l U
Initial pH = 2.10 13.7 mg/l Y
Initial emf = + 420 1400 mg/l Fe
0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	bio [U] mg/g	bio [Y] mg/g	bio [Fe] mg/g
5	103	14	1389	1.8	-	2.2
15	101	14	1432	2.2	-	-
30	100	14	1379	2.4	-	4.2
60	100	14	1400	2.4	-	-
120	94	13	1389	3.6	0.14	2.2

Comments:

- variation in solution content of U & Y
- no adsorption

Shaker Flask Adsorption Rate

Biomass = Actinomycetes % solids = 9.28
Viable (Live)

Conditions:

Temp = 24°C Other: Head = 91 mg/l U
Initial pH = 2.10 12.2 mg/l Y
Initial emf = + 420
0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	87	10.7	0.8	0.30
15	85	10.5	1.2	0.34
30	83	10.9	1.6	0.26
60	84	10.5	1.4	0.34
120	86	10.7	1.0	0.30

Comments:

Shaker Flask Adsorption Rate

Biomass = Actinomycete Inactivated % solids = 18.3

Conditions:

Temp = 24°C
Initial pH = 2.95 (NaOH)
Initial emf = + 400

Other: Head = 96.8 mg/l U
12.7 mg/l Y
40 mg/l Fe

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	bio [U] mg/g	bio [Y] mg/g
5	101	13	56	-	-
15	95	13	43	0.36	-
30	92	13	45	0.96	-
60	91	13	45	1.16	-
120	82	13	35	2.96	-

Comments:

- Biomass lumpy - not dispersed

Shaker Flask Adsorption Rate

Biomass = Actinomycete Inactivated % solids = 18.3

Conditions:

Temp = 24°C
Initial pH = 4.25
Initial emf = +340
0.5 g dry wt. biomass/100 ml soln.

Other = Head = 80 mg/l U
12.4 mg/l Y
4.4 mg/l Fe

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	bio [Fe] mg/g
5	54	13	6.6	32.5	5.2	-	-
15	41	12	5.4	48.8	7.8	0.08	-
30	56	13	5.2	30.0	4.8	-	-
60	48	13	4.5	40.0	6.4	-	-
120	42	12	5.0	47.5	7.6	0.08	-

Comments:

- Biomass lumpy

Shaker Flask Adsorption Rate

Biomass = Actinomycete % solids = 17.4
Younger Inactivated

Conditions:

Temp = 24°C Other = Head = 96 mg/l U
Initial pH = 2.10 11 mg/l Y
Initial emf = +420 1400 mg/l Fe
0.5 g dry wt. biomass/100 ml soln. Younger biomass

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	91	13	1.0	-
15	102	13	-	-
30	98	13	-	-
60	98	13	-	-
120	87	13	1.8	-

Comments:

- Biomass well dispersed

Shaker Flask Adsorption Rate

Biomass = Inactivated Actinomycete % solids = 14.3

Conditions:

Temp = 24°C
Initial pH = 1.95
Initial emf = N/A
0.5 g dry wt. biomass/100 ml soln.

Other: High Fe^{3+} Head = 103 mg/l U, 13.7 mg/l Y, 5210 mg/l Fe

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	sol [Fe] mg/l	bio [U] mg/g	bio [Y] mg/g	bio [Fe] mg/g
5	92.6	11.6	5000	2.08	0.42	42.0
15	88.4	11.6	4884	2.92	0.42	65.2
30	88.4	11.6	5042	2.92	0.42	33.6
60	91.6	11.6	4842	2.28	0.42	73.6
120	91.6	11.6	5316	2.28	0.42	-

Comments:

- Very good dispersion

Shaker Flask Adsorption Rate

Biomass = Actinomycete inactivated % solids = 12.3

Conditions:

Temp = 24°C
Initial pH = 2.35
Initial emf = N/A

Other: High SO_4^{2-}
Head = 95.8 mg/l U
12.6 mg/l Y
29 g/l SO_4

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	98.9	12.6	-	-
15	95.8	13.7	-	-
30	93.7	13.7	0.42	-
60	95.8	13.7	-	-
120	86.3	11.6	1.90	0.2

Comments:

- Very good dispersion

Shaker Flask Adsorption Rate

Biomass = Actinomycete inactivated % solids = 12.3

Conditions:

Temp = 24°C
Initial pH = 1.80
Initial emf = N/A
0.5 g dry wt. biomass/100 ml soln.

High PO_4^{3-}
Other: Head = 97.9 mg/l U
13.7 mg/l Y

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	95.8	13.7	0.42	-
15	93.7	13.7	0.84	-
30	94.7	13.7	0.64	-
60	94.7	13.7	0.64	-
120	94.7	13.7	0.64	-

Comments:

- Good dispersion. Rubber stopper began to disintegrate. Some pieces fell into solution.

Shaker Flask Adsorption Rate

Biomass = Actinomycete Inactivated % solids = 12.3

Conditions:

Temp = 24°C
Initial pH = 1.75
Initial emf = N/A

High Ca^{2+}
Other: Head = 94.7 mg/l U
= 12.6 mg/l Y
470 mg/l Ca

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	91.6	13.7	0.62	-
15	91.6	13.2	0.62	-
30	95.8	13.4	-	-
60	90.5	13.1	0.84	-
120	94.7	13.3	-	-

Comments:

- Very good dispersion.

Shaker Flask Adsorption Rate

Biomass = Actinomycete Inactivated

% solids = 18.03

Conditions:

Temp = 24°C

Other = High TOC (0.2 g of 2:1 Fuel oil:Axel Grease)

Initial pH = 1.90

= Head = 93 mg/l U

Initial emf = N/A

11 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	83	10.5	2.0	0.1
15	83	10.8	2.0	0.04
30	83	10.5	2.0	0.1
60	82	10.4	2.2	1.2
120	84	10.9	1.8	0.02

Comments:

Shaker Flask Adsorption Rate

Biomass = Actinomycete Inactivated % solids = 18.3

Conditions:

Temp = 12°C
Initial pH = 2.05
Initial emf = N/A

Other: Head = 91 mg/l U
= 12.2 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g
5	82	11.6	1.8	0.12
15	83	11.7	1.6	0.10
30	85	11.9	1.2	0.06
60	83	11.7	1.6	0.10
120	85	11.7	1.2	0.10

Comments:

Shaker Flask Adsorption Rate Test

Biomass = Actinomycete % solids = 18.00
Inactivated
Grown at pH = 2.3

Conditions:

Temp = 23°C Other: Head = 117.9 mg/l U
Initial pH = 2.15 15.2 mg/l Y
Initial emf = +410

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	115.8	14.5	1.78	2.1	0.7	4.61
15	117.9	15.5	-	-	-	-
30	118.9	15.5	-	-	-	-
60	112.6	15.7	4.50	5.3	-	-
120	113.6	14.5	3.65	4.3	0.7	4.61

Comments: Actinomycete grown at pH = 2.3
Mine water as received

Final pH = 1.90
emf = +615

Shaker Flask Adsorption Rate Test

Biomass = Actinomycete Inactivated % solids = 11.5

Conditions:

Temp = 24°C
Initial pH = 2.2
Initial emf = + 420

Other: High TSS* = 110 mg/l
Head = 103 mg/l U
13.7 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	87	12.9	15.5	3.2	0.16	5.8
15	87	13.1	15.5	3.2	0.12	4.4
30	90	13.3	12.6	2.6	0.08	2.9
60	91	12.9	11.7	2.4	0.16	5.8
120	94	14.5	8.7	1.8	-	-

Comments:

* TSS adjusted with acid washed ground Denision mill tailings.
- acid wash dilute H_2SO_4 (150 ml/l) at 20% solids for 1 hour.
- rinse with distilled water @ 10:1 wash ratio.

final pH = 2.1
emf = +420

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactivated % solids = 14.5

Conditions:

Temp = 21°C
Initial pH = 2.00
Initial emf = +620

Other: Head = 112 mg/l U
13.7 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	101	12.6	9.8	2.2	0.22	8.03
15	102	13.9	8.9	2.0	-	-
30	91	14.2	18.8	4.2	-	-
60	110	14.0	1.8	0.4	-	-
120	97	14.0	13.4	3.0	-	-

Comments: Mine solution as received

Final pH = 2.05
emf = +610

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive % solids = 14.0

Conditions:

Temp = 22°C
Initial pH = 2.95
Initial emf = +390

Other: Head = 93.4 mg/l U
12.8 mg/l Y
45.5 mg/l Fe

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	67.3	12.5	27.9	5.22	0.06	2.34
15	62.2	11.6	33.4	6.24	0.24	9.38
30	60.7	11.2	35.0	6.54	0.32	12.50
60	58.5	12.3	37.4	6.98	0.10	3.91
120	59.9	12.1	35.9	6.70	0.14	5.47

Comments: Mine solution adjusted to pH = 3 by addition of saturated NaOH solution

Final pH = 2.95
emf = +390

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive

% solids = 18.18

Conditions:

Temp = 23°C

Initial pH = 3.90

Initial emf = +290

Other: Head = 82.3 mg/l U
9.6 mg/l Y
0.8 mg/l Fe

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	38.5	9.5	53.2	8.76	0.02	1.04
15	32.2	8.9	60.9	10.02	0.14	7.29
30	29.1	9.6	64.6	10.64	-	-
60	23.6	9.4	71.3	11.74	0.04	2.08
120	19.5	9.2	76.3	12.56	0.08	4.17

Comments: Mine solution adjusted to pH = 3

Final pH = 3.55

emf = +310

Shaker Flask Adsorption Rate Test

Biomass = Penicillium % solids = 18.18
Inactive

Conditions:

Temp = 23°C
Initial pH = 2.00
Initial emf = +560

Other: Head = High Fe^{3+}
102.0 mg/l U
13.9 mg/l Y
5515 mg/l Fe

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	98.9	13.8	3.04	0.62	0.02	0.7
15	97.9	13.9	4.02	0.82	-	-
30	94.7	13.5	7.16	1.46	0.08	2.88
60	93.7	12.9	8.14	1.66	0.20	7.19
120	94.7	12.9	7.16	1.46	0.20	7.19

Comments: Mine water with 1.361 g/l Fe^{+3} added

Final pH = 1.80
emf = +530

Shaker Flask Adsorption Rate Test

Biomass = Penicillium
Inactive

% solids = 16.00

Conditions:

Temp = 22.0°C
Initial pH = 2.60
Initial emf = +475

Other: Head = High $SO_4^=$
97.9 mg/l U
12.5 mg/l Y
28.30 g/l $SO_4^=$

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	94.7	12.6	3.27	0.64	-	-
15	101.0	13.9	-	-	-	-
30	104.2	13.7	-	-	-	-
60	103.1	13.7	-	-	-	-
120	97.9	13.0	-	-	-	-

Comments: Mine water with 5.400 g/l $SO_4^=$ added

Final pH = 2.60
emf = +465

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive % solids = 15.09

Conditions:

Temp = 23°C
Initial pH = 1.95
Initial emf = +480

Other: Head = High PO_4^{3-}
100 mg/l U
12.8 mg/l Y
40.0 mg/l P

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	98.9	13.0	1.10	0.22	-	-
15	107.4	14.8	-	-	-	-
30	94.7	12.4	5.30	1.06	0.08	3.12
60	97.9	13.4	2.10	0.42	-	-
120	90.5	12.0	9.50	1.90	0.16	6.25

Comments: Mine solution with 0.026 g/l PO_4^{3-} added

Final pH = 2.05
emf = +445

Shaker Flask Adsorption Rate Test

Biomass = Penicillium
Inactive

% solids = 16.0

Conditions:

Temp = 22°C
Initial pH = 2.10
Initial emf = + 490

Other: Head = High Ca^{2+}
100.0 mg/l U
12.6 mg/l Y
497.4 mg/l Ca

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	88.4	12.5	11.6	2.32	-	-
15	94.7	13.7	5.30	1.06	-	-
30	100.0	14.7	-	-	-	-
60	96.8	14.4	3.20	0.64	-	-
120	100.0	15.0	-	-	-	-

Comments: Mine solution with 0.101 g/l Ca^{2+} added

Final pH = 1.95
emf = + 510

Shaker Flask Adsorption Rate Test

Biomass = Penicillium active (viable) % solids = 8.0%

Conditions:

Temp = 21.5°C
Initial pH = 2.10
Initial emf = +470

Other: Head = 104.2 mg/l U
13.3 mg/l Y
Live Biomass

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	97.9	12.4	6.05	1.26	0.18	6.77
15	93.7	12.2	10.08	2.10	0.22	8.27
30	96.8	12.2	7.10	1.48	0.22	8.27
60	97.9	12.4	6.05	1.26	0.18	6.77
120	102.1	12.4	2.02	0.42	0.18	6.77

Comments: Penicillium was used without going through a deactivation process.
Equilibrium test was not run

Final pH = 2.15
emf = +460

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive % solids = 23.52

Conditions:

Temp = 12°C
Initial pH = 2.10
Initial emf = +365

Other: Head = 123.1 mg/l U
18.2 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	114.7	17.5	6.82	1.68	0.14	3.85
15	108.4	17.9	11.94	2.94	0.06	1.65
30	108.4	16.8	11.94	2.94	0.28	7.69
60	108.4	16.8	11.94	2.94	0.28	7.69
120	105.2	17.4	14.54	3.58	0.16	4.40

Comments: Mine water held at 12°C in water while shaking
Temperature in bath remained constant at 12°C throughout test

Final pH = 2.00
emf = +365

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive % solids = 15.87

Conditions:

Temp = 22°C
Initial pH = 2.00
Initial emf = +370

Other: Head = 108 mg/l U
18.1 mg/l Y
High TOC = 480 mg/l

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	96	13.6	2.4	11.11	0.1	3.55
15	90	13.8	3.6	16.67	0.06	2.13
30	88	14	4.04	18.52	0.02	0.71
60	84	13.8	4.8	22.22	0.06	2.13
120	86	14	4.4	20.37	0.02	0.71

Comments: [TOC] final = 34 mg/l

Final pH = 2.10
emf = +365

Shaker Flask Adsorption Rate Test

Biomass = Penicillium Inactive % solids = 10.0

Conditions:

Temp = 24°C
Initial pH = 2.0
Initial emf = +420

Other: Head = 95 mg/l U
13.6 mg/l Y
High TSS* = 110 mg/l

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	90	13.4	1.0	5.3	0.04	1.5
15	87	13.2	1.6	8.4	0.08	2.9
30	88	13.2	1.4	7.4	0.08	2.9
60	87	13.3	1.6	8.4	0.06	2.2
120	87	13.4	1.6	8.4	0.04	1.5

Comments:

* TSS adjusted with acid washed ground Denison mill tailings
- Acid wash dilute H_2SO_4 (150 ml/l) at 20% solids for 1 hour
- rinse with distilled at 10:1 wash ratio

Final pH = 2.1
emf = +410

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 14.5

Conditions:

Temp = 21°C
Initial pH = 2.00
Initial emf = +620

Other: Head = 112 mg/l U
= 13.7 mg/l Y

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	% U ADS
0.1	100	13.4	2.05	+640	12.0	0. 3	10.7
0.5	97	14.0	2.05	610	3.0	-	13.4
1.0	80.5	13.2	2.10	530	3.15	0.05	28.1
2.0	67.3	12.0	2.20	550	2.24	0.09	39.9

Comments: Mine water as received.

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 14.5

Conditions:

Temp = 22°C

Initial pH = 2.95

Initial emf = +350

100 ml soln.

Other: Head = 93.4 mg/l U, 12.8 mg/l Y, 45.5 mg/l Fe (0.1 & 0.5)

104.2 mg/l U, 12.7 mg/l Y, 65.3 mg/l Fe (1.0 & 2.0)

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	Sol [Fe] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	60.2	11.8	-	2.95	380	33.2	1.0	35.5	7.8
0.5	54.9	12.1	-	2.95	390	6.70	0.14	35.9	5.47
1.0	67.4	12.1	25.3	2.90	360	2.6	0.07	27.8	5.5
2.0	37.9	11.7	7.8	3.15	320	2.8	0.055	59.4	8.6

Comments: Mine water adjusted to pH = 3 with saturated NaOH solution - two heads used (2 solutions)

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 18.18

Conditions:

Temp = 23°C
Initial pH = 3.90
Initial emf = +290

Other: Head = 82.3 mg/l U
= 9.1 mg/l Y
0.8 mg/l Fe

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	61.6	8.9	3.90	280	20.7	0.2	25.2	2.20
0.5	19.5	9.2	3.55	310	12.6	-	76.3	-
1.0	5.1	8.1	4.00	280	7.72	0.1	93.8	10.99
2.0	2.0	5.7	3.15	340	4.02	0.17	97.6	37.6

Comments: Mine water adjusted to pH = 4

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 18.18

Conditions:

Temp = 23°C

Initial pH = 2.00

Initial emf = +560

Other: High Fe^{3+} Head = 102.0 mg/l U
= 13.9 mg/l Y
= 5515 mg/l Fe

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	Sol [Fe] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	101.2	13.1	5189	1.80	540	0.8	0.8	0.78	5.76
0.5	94.7	12.9	5105	1.80	530	1.46	0.2	7.16	7.19
1.0	93.7	14.9	5021	1.80	560	0.83	-	8.14	-
2.0	85.3	14.5	4748	1.95	560	0.84	-	16.37	-

Comments: Mine water with 1.361 g/l Fe added

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 18.18

Conditions:

Temp = 21.5°C

Initial pH = 2.60

Initial emf = +500

Other: Head = High $SO_4^=$
97.9 mg/l U
12.5 mg/l Y
28.30 g/l $SO_4^=$

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	Sol [Fe] mg/l	Final pH sol	Final emf sol	bio [U] mg/g	% U ADS	% Y ADS
0.1	94.7	11.7	2.55	490	3.2	0.8	3.27	6.4
0.5	97.9	13.0	2.60	465	-	-	-	-
1.0	85.3	11.1	2.45	500	1.26	0.14	12.87	11.2
2.0	89.5	12.6	2.65	450	0.42	-	8.58	-

Comments: Mine water with 5.400 g/l $SO_4^=$ added

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = see below

Conditions:

Temp = 22°C
Initial pH = 2.10
Initial emf = +500

Other: High PO_4^{3-}
Head = 100.0 mg/l U
= 12.8 mg/l Y
= 40.0 mg/l P

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	emf sol	pH sol	Sol [P] mg/g	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1*	93.7	12.8	500	2.15	40.0	6.3	-	6.30	-
0.5**	90.5	12.0	445	2.05	36.8	1.9	0.16	9.50	6.25
1.0**	84.2	11.4	455	2.00	35.0	1.58	0.14	15.80	10.94

Comments: Mine water solution with 0.026 gm/l PO_4^{3-} added

* 18.18% solids
** 15.09% solids

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 23.52

Conditions:

Temp = 12°C
Initial pH = 2.10
Initial emf = +360

Other: Head = 123.1 mg/l U
= 18.2 mg/l Y

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	113.7	17.1	2.0	365	9.4	1.1	7.64	6.04
0.5	105.2	17.4	2.00	365	3.58	0.16	14.5	4.40
1.0	96.8	16.5	2.0	365	2.63	0.17	21.4	9.34
2.0	82.1	15.9	2.0	365	2.05	0.115	33.3	12.64

Comments: Mine water held at 12°C in water bath while shaking
Temperature in bath remained constant at 12°C throughout test.

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 10.0

Conditions:

Temp = 24°C
Initial pH = 2.0
Initial emf = +420

Other: High TSS* 110 mg/l
Head = 95 mg/l U
= 13.6 mg/l Y

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	88	13.0	7.0	0.6	7.4	4.4
0.5	87	13.4	1.6	0.04	8.4	1.5
1.0	75	12.8	2.0	0.08	21.05	5.9
2.0	66	11.8	1.45	0.09	30.5	13.2

Comments:

* TSS adjusted with acid washed ground.

- acid wash dilute H_2SO_4 (150 ml/l) at 20% solids for 1 hour

- rinse with distilled water @ 10:1 wash ratio

Equilibrium Adsorption

Biomass = Pencillium inactivated

% solids = 15.87

Conditions:

Temp = 22°C
Initial pH = 2.00
Initial emf = +370

Other: Head = 108 mg/l U
= 14.1 mg/l Y
High TOC* = 480 mg/l

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	[TOC] mg/l	bio [U] mg/g	bio [Y] mg/g	% U ADS	% Y ADS
0.1	97	13.7	2.00	+365	20	11.0	10.19	0.4	2.84
0.5	86	14.0	2.10	+365	34	4.4	20.37	0.02	0.71
1.0	76	13.0	2.10	+365	54	3.2	29.63	0.11	7.80
2.0	58	12.0	2.10	+350	60	2.5	46.30	0.105	14.89

Comments:

* adjusted by adding 2:1 mixture of fuel oil:axel grease

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : NaCl 0.1N

Conditions:

Temp: 22°C

Initial pH: 5.65

Init. emf : N/A

0.5 g dry Biomass (loaded) /100 ml solution

Sample Time (mins)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
5	<0.5	.07	3.925	0.216	2.48
15	<0.5	.03	"	0.224	"
30	<0.5	.04	"	0.222	"
60	<0.5	.03	"	0.224	"
120	<0.5	.07	"	0.216	"

Comments:

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : NaCl 0.02N

Conditions:

Temp: 22°C

Initial pH: 5.6

Init. emf : N/A

0.5 g dry Biomass (loaded) /100 mL solution

Sample Time/mins	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
5	<0.5	0.02	3.925	0.226	2.48
15	<0.5	0.05	"	0.22	"
30	<0.5	0.06	"	0.218	"
60	<0.5	0.04	"	0.222	"
120	<0.5	0.07	"	0.216	"

Comments:

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : Na_2CO_3 0.02N

Conditions:

Temp: 22°C

Initial pH: 10.65

Init. emf : N/A

0.5 g dry Biomass (loaded) /100 mL solution

Sample Time (mins)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
5	15	0.43	1.025	0.144	74.5
15	15	0.42	1.025	0.146	74.5
30	16	0.36	0.825	0.158	79.5
60	17	0.30	0.625	0.17	84.5
120	18	0.30	0.425	0.17	89.4

Comments:

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : Na_2CO_3 0.1N

Conditions:

Temp: 22°C

Initial pH: 11.05

Init. emf : N/A

0.5 g dry Biomass (loaded) /100 ml solution

Sample Time/mins	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
5	18	0.67	0.425	0.096	89.4
15	19	0.86	0.225	0.058	94.4
30	18	0.81	0.425	0.068	89.4
60	18	0.84	0.425	0.062	89.4
120	20	0.82	0.025	0.066	99.4

Comments:

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : 0.1 N H_2SO_4

Conditions:

Temp: 22

Initial pH: 1.9

Init. emf : N/A

0.5 g dry Biomass (loaded) /100 mL solution

Sample Time/mins	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
5	4.1	0.66	3.205	0.098	20.4
15	3.8	0.69	3.265	0.092	18.9
30	3.3	0.66	3.365	0.098	16.4
60	3.2	0.66	3.385	0.098	15.9
120	3.0	0.68	3.425	0.094	14.9

Comments:

Shaker Flask Desorption Rate Test

Biomass : Actinomycete Inactive
Loaded to 4.025 mg/g U

Desorbant : 0.02 N H_2SO_4

Conditions:
Temp: 22°C
Initial pH: 4.55
Init. emf : +280

0.5 g dry Biomass (loaded) /100 ml solution

% solids : 11.5

Sample Time/mins	sol U g/l	sol Y g/l	% U Des.	Bio U mg/g
5	0.5	0.22	2.5	3.93
15	<0.5	0.09	2.5	3.93
30	<0.5	0.18	2.5	3.93
60	<0.5	0.09	2.5	3.93
120	<0.5	0.46	2.5	3.93

Comments:

Shaker Flask Desorption Rate Test

Actinomycete Inactive

Various Tests

0.5g biomass/100 ml Soln. 120 minutes duration
loaded @ pH 4.0
4.025 mg/g U 0.23 mg/g Y

Desorbant	sol [U] mg/l	sol [Y] mg/l	bio [U] mg/g	bio [Y] mg/g	% desorption U	% desorption Y
1M Mg_2SO_4	0.6	1.8	3.905	-	2.98	156.0
1M NaCl	0.8	0.61	3.865	0.108	3.98	53.0
1M Na_2CO_3	25.0	1.5	-	-	124.0	130.0
1M Na_2SO_4	1.1	1.0	3.805	0.03	5.47	87.0
0.1M H_2SO_4	17.0	1.2	0.625	-	84.5	104.0

Equilibrium Desorption Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y
(adsorbed at pH 4.0)

Desorbant : NaCl 0.1N

Conditions:
Temp: 22°
Initial pH: 5.65
Init. emf : N/A
Time/min : 120

Dry Biomass gr	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
0.1	0.51	0.03	3.515	0.20	12.7
0.5	<0.5	0.07	3.92	0.216	12.48
1.0	<0.5	0.09	3.975	0.221	1.24
2.0	0.65	0.14	3.992	0.223	0.81

Equilibrium Desorption Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : NaCl 0.02 N

Conditions:

Temp: 22°C

Initial pH: 5.6

Init. emf : N/A

Time/min : 120

Dry Biomass (g)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
0.1	<0.5	0.03	3.525	0.20	12.4
0.5	<0.5	0.07	3.925	0.216	2.48
1.0	<0.5	0.15	3.975	0.215	1.24
2.0	<0.5	0.23	4.00	0.219	0.62

Equilibrium Desorption Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : Na_2CO_3 0.02 N

Conditions:

Temp: 22°C

Initial pH: 10.65

Init. emf : N/A

Time/min : 120

Dry Biomass (g)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
0.1	3.8	0.08	0.225	0.15	94.4
0.5	18.0	0.30	0.425	0.17	89.4
1.0	39.0	0.59	0.125	0.171	96.9
2.0	77.0	1.30	0.175	0.165	95.7

Equilibrium Desorption Test

Biomass : Actinomycete — 4.025 mg/g U 0.23 mg/g Y
Inactive — (adsorbed at pH 4.0)
Desorbant : Na_2CO_3 0.1N

Conditions:
Temp: 22°C
Initial pH: 11.05
Init. emf : N/A
Time/min : 120

Dry Biomass (g)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
0.1	5.0	0.20	-	0.03	124
0.5	20.0	0.82	0.025	0.06	99.3
1.0	40.0	1.61	0.025	0.07	99.4
2.0	82.0	2.92	-	0.08	102

Equilibrium Desorption Test

Biomass : Actinomycete Inactive — 4.025 mg/g U 0.23 mg/g Y (adsorbed at pH 4.0)

Desorbant : H_2SO_4 0.1N

Conditions:

Temp: 22°C

Initial pH: 1.9

Init. emf : N/A

Time/min : 120

Dry Biomass (g)	sol U g/l	sol Y g/l	Bio U mg/g	Bio Y mg/g	% Des. U
0.1	1.41	0.19	2.615	0.04	35.0
0.5	3.0	0.68	3.425	0.09	14.9
1.0	3.6	1.13	3.665	0.117	8.9
2.0	3.9	1.84	3.83	0.138	4.8

Shaker Flask Desorption Rate Test

Biomass = Penicillium Inactive

% solids = 33.54

Desorbant = 0.1 N Na_2CO_3

Conditions:

Temp = 23°C

biomass loaded to 13 mg/g

Initial pH = 10.60

Initial emf = -2.5

0.5 g dry wt. biomass (loaded)/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U DES.	bio [U] mg/g	bio [Y] mg/g	% Y DES.
5	62	0.15	95.4	0.6	-	-
15	82	0.17	-	0	-	-
30	77	0.21	-	0	-	-
60	83	0.24	-	0	-	-
120	87	0.25	-	0	-	-

Comments:

Shaker Flask Desorption Rate Test

Biomass = Penicillium Inactive

% solids = 33.54

Desorbant = 0.1 N Na_2SO_4

Conditions:

Temp = 23°C

biomass loaded to 13 mg/g

Initial pH = 1.70

Initial emf = + 395

0.5 g dry wt. biomass (loaded)/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U DES.	bio [U] mg/g	bio [Y] mg/g
5	41.6	0.31	64.0	4.68	-
15	35.4	0.23	54.5	5.92	-
30	42.8	0.27	65.8	4.44	-
60	42.4	0.28	65.2	4.52	-
120	42.8	0.29	65.8	4.44	-

Comments:

Shaker Flask Desorption Rate Test

Biomass = Penicillium
Inactive

% solids = 12.0

Desorbant = 0.1 N NaCl

Conditions:

Temp = 21°C

biomass loaded to 16.4 mg/g

Initial pH = 6.35

Initial emf = + 160

0.5 g dry wt. biomass (loaded)/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U DES.	bio [U] mg/g	bio [Y] mg/g
5	4.5	0.37	69.2	4.0	-
15	2.7	0.33	41.5	7.6	-
30	5.3	0.39	81.5	2.4	-
60	5.1	0.41	78.5	2.8	-
120	6.4	0.46	98.5	0.2	-

Comments:

Equilibrium Desorption Test

Biomass: Penicillium Inact. 20% solids

Desorbant: 0.1N Na_2CO_3

Conditions

Temp. = 22°C
init. pH = 11.15
init. emf = 90
Time (mins) = 120 vol
Vol. Sol. = 100 ml

bio. initial loading = $\frac{U}{16\ mg/g}$

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	13.6	11.2	-120	85.0	2.4
0.5	48.4	11.1	-110	60.5	6.32
1.0	101	10.95	- 90	63.1	5.9
2.0	188	10.85	- 70	58.8	6.6

Comments:

Equilibrium Desorption Test

Biomass: Penicillium Inact. 20% solids

Desorbant: 0.1N H_2SO_4

Conditions

Temp. = 22°C
init. pH = 1.60
init. emf = +260
Time (mins) = 120 vol
Vol. Sol. = 100 ml

bio. initial loading = $\frac{U}{12\ mg/g}$

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	8.7	1.75	+260	72.5	3.3
0.5	35	1.65	+260	58.3	5.0
1.0	62	1.65	+260	51.7	5.8
2.0	101	1.65	+260	42.1	6.95

Comments:

Equilibrium Desorption Test

Biomass: Penicillium Inact. 20% solids

Desorbant: 0.1N NaCl

Conditions

Temp. = 22°C
init. pH = 4.10
init. emf = +200
Time (mins) = 120 vol
Vol. Sol. = 100 ml

bio. initial loading = $\frac{U}{7\ mg/g}$

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	1.3	4.35	+200	18.6	5.7
0.5	3.1	3.95	+190	8.9	6.4
1.0	2.9	4.15	+210	4.1	6.7
2.0	3.6	4.05	+200	2.5	6.8

Comments:

Shaker Flask Adsorption Rate Test

Biomass = Rhizopus Inactive

% solids = 14

Conditions:

Temp = 21°C
Initial pH = 2.10
Initial emf = +365

Other: = mine water as-rec'd
Head = 97 mg/l U
= 12.8 mg/l Y

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	sol [Y] mg/l	% U ADS	bio [U] mg/g	bio [Y] mg/g	% Y ADS
5	95	12.6	2.06	0.4	0.04	1.56
15	91	12.3	6.19	1.2	0.1	3.91
30	89	12.3	8.25	1.6	0.1	3.91
60	88	12.6	9.28	1.8	0.04	1.56
120	75	10.7	22.68	4.4	0.56	21.88

Comments:

Final pH = 2.10
emf = +460

Shaker Flask Adsorption Rate Test

Biomass = Rhizopus Inact. % solids = 19.2

Conditions:

Temp = 22°C
Initial pH = 3.90
Initial emf = +200
Other: sol'n. adjusted with NaOH
Head = 94 mg/l U

0.5 g dry wt. biomass/100 ml soln.

Sample Time (mins.)	sol [U] mg/l	% U ADS	bio [U] mg/g
5	83.6	11.1	2.08
15	72.2	23.2	4.36
30	63.4	32.6	6.12
60	53.8	42.8	8.04
120	42.4	54.9	10.32

Comments:

Final pH = 3.70
emf = +210

Equilibrium Adsorption

Biomass = Rhizopus I
Inactivated

% solids = 14.0

Conditions:

Temp = 21.0°C
Initial pH = 2.05
Initial emf = +480

Other: Minewater as rec'd.
Head = 97 mg/l U
= 12.8 mg/l Y

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	sol [Y] mg/l	pH sol	emf sol	bio [U] mg/g	% U ADS	bio [Y] mg/g	% Y ADS
0.1	96	12.9	2.05	+480	1.0	1.03	-	-
0.5	75	10.7	2.10	+460	4.4	22.68	0.42	16.41
1.0	74	11.5	2.10	+460	2.3	23.71	0.13	10.16
2.0	57	10.5	2.10	+440	2.0	41.24	0.115	17.97

Comments:

Equilibrium Adsorption

Biomass = Rhizopus inactivated

% solids = 19.2

Conditions:

Temp = 22°C
Initial pH = 3.90
Initial emf = + 200

Other: Head = 94 mg/l
sol'n. adjusted with NaOH

100 ml soln.

Biomass dry wt (g)	sol [U] mg/l	pH sol	emf sol	bio [U] mg/g	% U ADS
0.1	84.5	-	+200	9.5	10.1
0.5	42.4	3.75	+210	10.3	54.9
1.0	26.1	3.85	+180	6.79	72.2
2.0	8.4	3.95	+200	4.28	91.1

Comments:

Shaker Flask Desorption Rate Test

Biomass : Rhizopus
Inact.

Desorbant : 0.1N Na_2CO_3

Conditions:
Temp: 25°C
Initial pH: 11.50
Init. emf : -60

bio initial loading = 25 mg/g U
2.3 mg/g Y
15.68% solids

0.5 g dry Biomass (loaded) /100 ml solution

Sample Time/mins	sol U g/l	% U Des.	Bio U mg/g
5	10.8	8.64	22.84
15	20.8	16.6	20.84
30	27.7	22.1	19.48
60	38.0	30.4	17.40
120	49.0	39.2	15.20

Comments:

final pH = 10.6
final emf = - 62

Shaker Flask Desorption Rate Test

Biomass : Rhizopus
Inact.

Desorbant : 0.1N H_2SO_4

Conditions:
Temp: 25°C
Initial pH: 1.55
Init. emf : +360

bio initial loading = 25 mg/g U
2.3 mg/g Y

0.5 g dry Biomass (loaded) /100 ml solution

Sample Time/mins	sol U g/l	% U Des.	Bio U mg/g
5	13.3	10.6	22.34
15	18.5	14.8	21.3
30	23.1	28.5	20.4
60	26.5	21.2	19.7
120	40.1	24.1	18.98

Comments:

final pH = 1.55
final emf = +370

Shaker Flask Desorption Rate Test

Biomass : Rhizopus
Inact.

Desorbant : 0.1N NaCl

Conditions:
Temp: 25°C
Initial pH: 5.70
Init. emf : +160

bio initial loading = 13.7 mg/g U
14.53% solids

0.5 g dry Biomass (loaded) /100 ml solution

Sample Time/mins	sol U g/l	% U Des.	Bio U mg/g
5	0.5	0.73	13.6
15	1.0	1.46	13.5
30	1.6	2.34	13.38
60	1.7	2.48	13.36
120	2.4	3.50	13.22

Comments:

final pH = 5.65
final emf = +180

Equilibrium Desorption Test

Biomass: Rhizopus
Inact.

Desorbant: 0.1N Na_2CO_3

Conditions

Temp. = 25°C
init. pH = 11.10
init. emf = -60
Time (mins) = 120
Vol. Sol. = 100 ml

bio. initial loading = 25 mg/g U
2.3 mg/g Y
15.68% solids

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	9.9	11.1	0	39.6	15.1
0.5	49.0	10.6	- 62	39.2	15.2
1.0	86.7	10.3	- 62	34.7	16.33
2.0	170.6	10.0	- 20	34.1	16.47

Comments:

Equilibrium Desorption Test

Biomass: Rhizopus
Inact.

Desorbant: 0.1N H_2SO_4

Conditions

Temp. = 25°C
init. pH = 1.55
init. emf = +360
Time (mins) = 120 vol
Vol. Sol. = 100 ml

bio. initial loading = 25 mg/g U
2.3 mg/g Y

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	8.5	1.55	+400	34.0	16.50
0.5	30.1	1.55	+370	24.1	18.98
1.0	54.2	1.55	+370	24.7	19.58
2.0	88.9	-	-	17.8	20.56

Comments:

Equilibrium Desorption Test

Biomass: Rhizopus
Inact.

Desorbant: 0.1N NaCl

Conditions

Temp. = 25°C
init. pH = 5.75
init. emf = +160
Time (mins) = 120 vol
Vol. Sol. = 100 ml

bio. initial loading = 13.7 mg/g U
14.53% solids

Dry Wt. Biomass (g)	sol U g/l	Final pH	Final emf/	% Des. U	Bio U mg/g
0.1	<0.2	4.75	+160	-	-
0.5	2.4	5.65	+180	3.50	13.22
1.0	3.7	3.65	+170	2.70	13.33
2.0	4.5	3.50	+190	1.64	13.48

Comments:

TABLE OF CONTENTS

		Page No.
Executive Summary		1
Recommendations For Further Work		4
Program Objective		5
Phase I Report - Development of Detailed Workplan		
1.	Introduction	6
2.	Production of Biomasses and Performance of Testwork	6
3.	Evaluation of Biomasses	8
Phase II Report - Performance of Testwork		
1.	Production of Biomass	10
1.1	Stock Cultures	10
1.2	Culture Medium	10
1.3	Culture Conditions	12
1.4	Large-Scale Cultures of Test Organisms	12
1.4.1	Actinomycete	12
1.4.2	Acidophilic Rhizopus Species	14
1.4.3	Rhizopus arrhizus and Acidophilic Penicillium Species	14
1.5	Harvesting of Biomass	15
1.6	Heat Shocking	15

TABLE OF CONTENTS (Cont'd.)

		Page No.
1.7	Results and Discussion	16
1.7.1	The Organisms	16
1.7.2	Culture Conditions	17
1.7.3	Biomass Description	17
1.7.4	Conclusions	19
1.8	Comments on Biomass Production	19
2.	Biosorption Studies	20
2.1	Experimental Procedures	20
2.1.1	Batch Adsorption Rate Tests	21
2.1.2	Batch Equilibrium Adsorption Tests	22
2.1.3	Batch Desorption Rate Tests	23
2.1.4	Equilibrium Desorption Tests	23
2.1.5	Continous Actinomycete Shaker Tests	24
2.1.6	Column Tests	25
2.2	Results and Discussion	26
2.2.1	Batch Adsorption Tests	26
2.2.2	Batch Desorption Tests	30
2.2.3	Actinomycete Continuous Tests	33
2.2.4	Column Tests	35
	Phase III Report - Evaluation of Biomasses	
1.	Introduction	90
2.	Penicillium	92
2.1	Flowsheet Development	92
2.1.1	pH Adjustment	92

TABLE OF CONTENTS (Cont'd.)

		Page No.
2.1.2	Biomass Loading and Elution	92
2.1.3	Selection of Eluant	93
2.1.4	Yellowcake Precipitation	94
2.1.5	Eluant Carbonation	94
2.1.6	Biomass Fermentation	94
2.2	Conceptual Flowsheet	95
2.3	Design Criteria	97
2.4	Culture Requirements and Cost of Nutrients	97
2.5	Ease of Scale-Up	99
2.5.1	Mass and Energy Balance Considerations	99
2.5.2	Process Control	100
2.5.3	Liquid/Solid Contacting	100
2.5.4	Liquid/Solid Separation	101
2.5.5	Materials Handling	101
2.5.6	Type of Equipment and Materials of Construction	101
2.5.7	Generation of Contaminants and Desired Products	102
2.5.8	Nutrient Requirements	102
2.6	Major Technical Problems	102
3.	Actinomycete	103
3.1	Flowsheet Development	103
3.1.1	General	103
3.1.2	Liquid/Solid Contacting	104
3.1.3	Liquid/Solid Separation	104
3.2	Design Criteria	104
3.3	Culture Requirements and Cost of Nutrients	105
3.4	Major Technical Problems	106

TABLE OF CONTENTS (Cont'd.)

		Page No.
4.	Rhizopus Arrhizus	106
4.1	Flowsheet Development and Conceptual Flowsheet	106
4.2	Design Criteria	107
4.3	Culture Requirements and Cost of Nutrients	107
4.4	Ease of Scale-Up and Major Technical Problems	107